STATUS OF TREE BREEDING FOR MAJOR COMMERCIAL TREE SPECIES IN KENYA

KEFRI - GATSBY AFRICA (KCFP) COMMERCIAL FORESTRY PROJECT REPORT

A SUMMARY REPORT

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EXECUTIVE SUMMARY

Tree breeding is the cornerstone of commercial forestry, as it provides the means through which tree growers' access superior germplasm to optimize tree and forest productivity. It is market driven through demand of certain products and forms an integral component of forest plantation programmes globally. The process of tree breeding is long-term includes involves selection of superior trees based on heritable traits of importance, multiplication of selected genotypes, inter-mating of selections and genetic testing. Therefore adequate planning which includes identification of future demands and based on local wood products, market dynamics, and the global trends is required. The ultimate goal of tree breeding is the development of highly yielding varieties of priority tree species for industrial plantation programmes, stress resistant varieties for marginal sites, improved nitrogen fixing trees for agroforestry systems; and improved varieties for fuel wood or bioenergy production. Implementation of tree breeding programmes is achieved through strategies that are drawn per priority species, with objectives of breeding being clearly defined. It also takes into account the markets for the desired end-products as well as the unique biological attributes of the species.

In Kenya, tree-breeding programmes have been implemented at varying levels of intensity since 1936. The intensity ranges from introduction (germplasm infusion) of exotic species and testing their performance in various sites, domestication of potential indigenous species, testing of provenances of key species, and finally mass selection of superior genotypes of key species. This was then followed by establishment of seed orchards and testing the performance of the progenies of the selections in F1 generation. However, progression into developing F2 generation from the best performers in the F1 generation of the species was never systematic hence gaps in most of the breeding programmes.

Tree species that have been focused on for breeding are the three highlands fast growing exotic timber species namely: *Cupressus lusitanica*, *Pinus patula* and *Pinus radiata*. Subsequent expansion of the programme included lowlands pines and later involved diversification of priority species such as *Eucalyptus grandis*, *E. urophylla*, *E. camaldulensis*, *Grevillea robusta*, *Markhamia lutea* and *Gmelina arborea*. More recently, two indigenous species; *Melia volkensii* and *Acacia tortilis* have been incorporated under breeding for drought tolerance. Over time, the breeding programmes have been reviewed and some species such as *P. radiata* have been discontinued due to pests and disease. The breeding

work done on *C. lusitanica*, *P. patula* and *E. grandis* has yielded improved germplasm whose productivity levels are currently at Mean Annual Increment (MAI) of 25, 30, and 50 m^3 $ha^{-1}yr^{-1}$. For continued improvement and to ensure provision of high quality germplasm for commercial plantation ventures, this report provides a detailed review of the current status of breeding programmes of major commercial plantation species in Kenya. The species reviewed include; *Eucalyptus grandis, Eucalyptus urophylla, P. patula, C. lusitanica, G. robusta, M. volkensii, Casuarina equisitifolia,* and *Casuarina junghuhniana*. In addition to reporting on status, the information obtained and the gaps identified in this review enabled the formulation of the way forward, which comprises clear roadmaps and breeding strategies for each species aimed at achieving higher productivity

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1.0 Introduction

Globally, forest tree breeding started in mid twentieth century, and since then, the use of improved material for forest regeneration has become an essential part of forestry in many countries. The demand for forest tree seed and planting stock has increased rapidly, and frequently exceeds the supply. Due to high demand, most nurseries do not stock material of high genetic quality and known origin.

Forest tree breeding is an integral part of modern silviculture that is used to increase the economic profitability of wood production (White *et al.,* 2007). More consideration is currently given to the quality of planting material, which is achieved through tree-breeding programmes. Tree breeding modifies the genetic composition of the tree population to better fulfil the human needs, as natural selection has not produced the best material for the desires of man. The biotic and abiotic components of the environment are continuously changing so that historical adaptations can be out-of-date in current situations (Pâques, 2013). Climate change can increase the need of artificial forest regeneration and forest tree breeding. Tree breeding can accelerate the adaptation of the trees to changing environments (Savolainen *et al*. 2004; Rehfeldt et al. 2014). Forest tree breeding is an integral part of bio-economy in securing the production of good quality raw materials in large quantities and will have a significant economic impact on the profitability of forestry in the long term.

Tree improvement programmes have been implemented in Kenya at varying levels of intensity since 1936 in order to address the deficit of wood supply, which is currently estimated at 15 million m^3 per annum. However, the status of breeding programmes of many tree species in Kenya is not well known. In this report, current breeding programmes of the major commercial plantation tree species (Eucalypts, pines, Casuarinas, *Melia volkensii*, *Grevillea robusta* and *Cupressus lusitanica*) in Kenya are reviewed.

2.0 Eucalyptus species

2.1 Background

The Genus *Eucalyptus* comprises more than 900 species and unknown number of hybrids and varieties (Boland *et al.,* 2006). Most *Eucalyptus* species occur naturally in Australia, however, a few species are naturally found in Philippines, Papua New Guinea, Indonesia and Timor. Eucalypts are among the most widely cultivated forest trees in the world. Their adaptability, relatively fast growth rate, coppice ability, diverse utility value and broad climatic range have endeared them to tree growers. Most planting of eucalypts have been established to supply fibre for pulpwood markets, however interest is increasing for other products including solid wood, veneer, charcoal and biomass (KFS, 2009; Oballa *et al.,* 2010). Eucalypts are among the most widely cultivated forest trees in the world, covering over 20million hectares. The major *Eucalyptus* growing countries are China with 4.5 million ha; India 3.9 million ha and Brazil 5.7 million ha (IUFRO, 2018). In Africa, South Africa has the largest acreage of *Eucalyptus* plantations of about half a million hectares followed by Ethiopia (Teketay, 2003). It is estimated that there are 320 000 ha of *Eucalyptus* grown by Kenya Forest Service (KFS), private sector, and large and small-scale farmers (Oballa *et al.,* 2010). The productivity of managed *Eucalyptus* forests has increased from 12 m^3 ha-1 yr-1 in the 1960s to 70 m^3 ha-1 yr-1 due to improved genetics and silviculture in the tropics (Forester *et al* 2013).

About 100 *Eucalyptus* species have been introduced to Kenya and 83 have been planted at various times at KEFRI Arboretum, Muguga (Gottneid and Thogo, 1975). Out of the 83 species planted in the arboretum only 71 have survived. Of these; 4 are fast growing, 14 are moderate, and 53 are slow growing. Kenya Forestry Research Institute (KEFRI) through reintroduction, selection and breeding, has developed fast-growing eucalyptus trees with straight stems that attain mean annual volume growth of above 45 $m^3ha^{-1}yr^{-1}$ and height of 5 m per year between ages 3 and 5 years (Oballa and Giathi, 1996).

The most widely grown *Eucalyptus* species in Kenya are *E. grandis, E. saligna, E. camaldulensis* and *E. globulus*. Other species planted on small scale are *E. regnans, E. paniculata, E. maculata* (Syn. *Corymbia maculata*) and *E. citriodora* (Syn.*C.citrodora*) (Oballa *et. al* 2010). Hybrids of Grandis x Camaldulensis (GC) are also planted in mid-altitudes between 1200 and 1600m above sea level (asl), and at much lower sites along the coastal region with rainfall above 600 mm (Muchiri *et al.,* 2005; RELMA, 2006). *Eucalyptus* *urophylla* has gained popularity in the Lake Victoria Basin, more so in areas below 1400 m above sea level (asl) because of its fast growth, straight stem form, low infestation by most *Eucalyptus* pests and diseases and high utility value (KFS, 2009; Oballa *et. al* 2010).

2.2 Base population for Eucalyptus *species*

The major sources of Eucalyptus germplasm in Kenya is from plantations established by KFS and the private sector including Brooke Bond, James Finlays Ltd, Eastern Produce and British American Tobacco (BAT), who use wood energy for industrial processing. Other companies such as Kakuzi Ltd. grow *Eucalyptus* species to process into products that are in great demand in the market such as power transmission poles, fencing posts and firewood. In the past, selected seedling seed stands for *E. grandis* in Turbo, Nyeri and Muguga remained major sources of seed. These stands had better growth performance and provided seed that were used for establishing most current *E.grandis* plantations in Tea Estates and KFS.

Kenya Forestry Research Institute has established several trials for tree improvement purposes. These include arboretum plots in Muguga, progeny trials from 338 selected superior *E. grandis* in Kamara and Sotik, 55 *E. urophylla* and 43 *E. camaldulensis* in Yala Swamp and Maseno. Selected superior trees were used to establish 15 ha of seed orchards in Turbo and progeny trials in Turbo and Londiani. Recently introduced germplasm of *E.grandis* tested in Turbo, Kakuzi, Nyeri and Muguga form additional populations where selections can be conducted for candidate plus tree. Selection can also be conducted within progeny trials and a species trial of *E. camaldulensis* subspecies "zanzibarica" planted in Ramogi.

2.3 Breeding strategies of E. grandis and *E. urophylla*

National Tree Improvement Strategy 2018 – 2043 has identified *E. grandis* among tree species prioritized for intensive tree improvement programme whilst *E. saligna*, *E. camaldulensis* and *E. urophylla* are categorized highly for tree species diversification. To address the issues of climate change, the improvement of *E. urophylla* is imperative, due to its resilience. Furthermore, the species has gained popularity among forest plantation farmers. Therefore, this document will focus on the breeding strategies of *E. grandis* and *E. urophylla*.

2.3.1 E. grandis

Breeding objectives:

The primary markets of *E.grandis* are sawn timber and transmission poles. *E.grandis* will also be used as a main parent in hybrid production. The breeding objectives will be improved productivity, which encompasses fast growth, lower wood splitting, improved tree health and improved tree form. The breeding strategy of *E. grandis* is shown in Figure 1.

2.3.1.1 Current genetic resources

The origin of the *E. grandis* breeding populations can be traced back to imports of families from Australia in 1989 and various bulk seeds from Zimbabwe and South Africa. Selections were made in KFS and tea estates plantations (James Finlay, George Willamson, Sotik Highlands and Unilever), which originated from these sources and established in a series of F1 progeny trials at Kamara, Turbo and Sotik in 2004-2016. A further 111 families of various provenances imported from Australia through Camcore were established in 2019, as new infusions to broaden the genetic base.

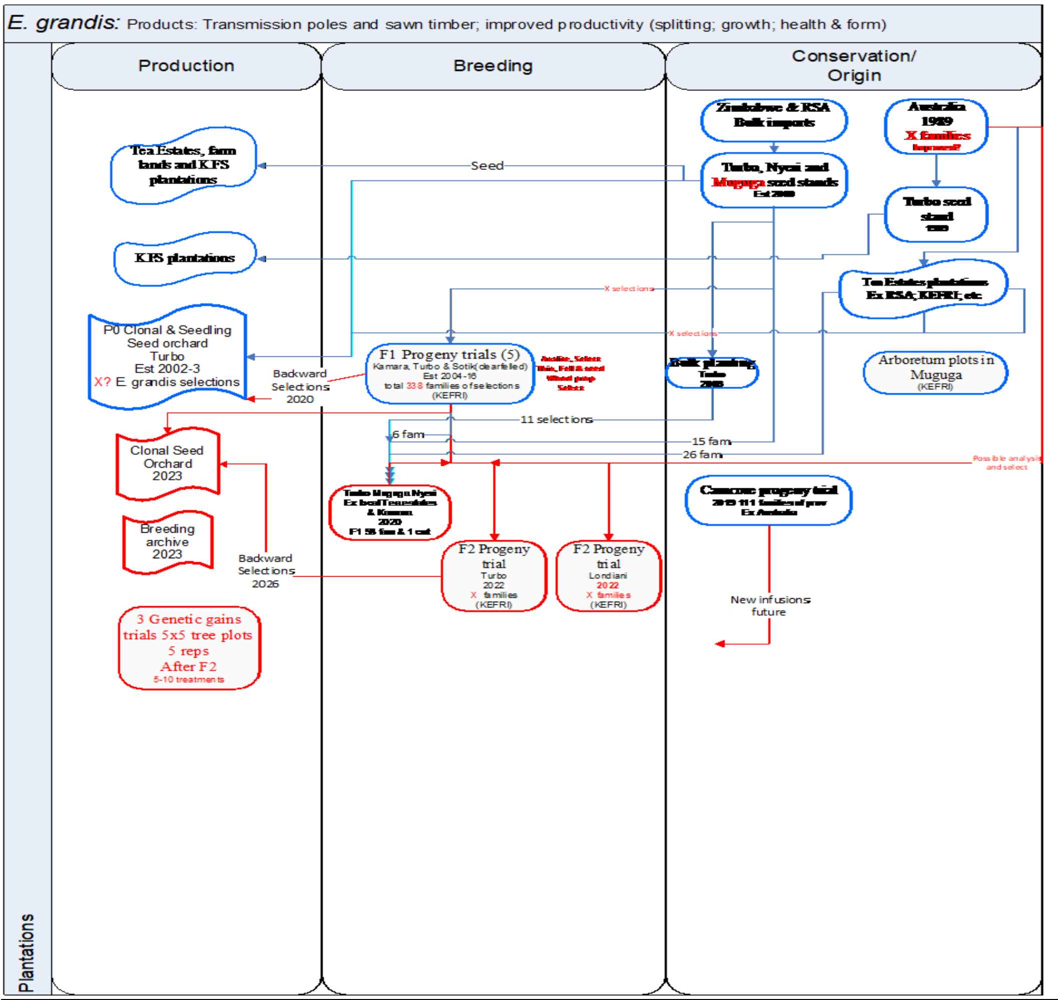

Figure 1: *Eucalyptus grandis* breeding strategy in Kenya

2.3.1.2 Planned activities and interventions

The following plans were identified to accelerate the breeding and improvement of the *E. grandis* genetic resource

1. Analysis and selection from Australian collection together with selections from Turbo, Nyeri and the Tea estates to form a new F1 progeny trial series of 58+ families to be planted at Turbo, Muguga and Nyeri in 2020.
2. Develop the F2 progeny trial series with a large number of F2 families (approximately 150). These will form the key advanced generation breeding population for KEFRI. The population will be advanced further to F3 in approximately 2027. At that stage, it is envisioned to infuse more genetic diversity (selections) from the Camcore trials and other new infusions.
3. Enrich the P0 (initial breeding population) clonal and seedling seed orchard by rogueing the poorer families/clones from these orchards using the family rankings in the F1 progeny trials as scheduled in 2020.
4. Initiate the process of analyzing and selecting in the F1 progeny trials for a new clonal seed orchard and a breeding archive (tree bank). The same analysis of the F1 progeny trial will also be used to identify and collect material for the F2 progeny trials. The steps involved the selection process of the F1 progeny trials are:
    - Analyze the phenotypic values being measured (height, DBH, health and form) and identify 1st round selections
    - Thin the trials in order to enrich the pollen cloud
    - Allow a season of pollination
    - Clear fell the trials, assess the wood properties and collect seed from the 1st round selections
    - Carry out a 2nd round of selections removing the poor wood properties genotypes from the collected seeds
    - Use the 2nd round selections for the F2 progeny trials as well as clones for the new generation clonal seed orchards

5. Establish 3 genetic gains trials with the purpose of measuring the percentage improvement of the F2 over the F1 and over commercial controls. These trials can also be used for field days and demonstration purposes.

2.3.2 Eucalyptus urophylla

Eucalyptus urophylla has been identified as a species of high importance and potential for the following reasons:

- It is known to be a vigorous species in terms of growth and health
- Its solid wood properties are reported to be of potential to the timber industry
- The species originates from the tropical and monsoonal areas and as such has wide adaptability, which is known to cope with climatic extremes especially in terms of rainfall.
- *E. urophylla* is widely used as a hybrid partner in the *E. grandis* x *E. urophylla* (GxU) hybrids, which are reputed to have high growth attributes, as well as tolerance to pests and diseases (e.g *Leptocybe invasa*).
- Internationally this species is gaining interest for sawn timber, however limited breeding has been undertaken to date. There is therefore need and opportunity for KEFRI to take the lead in improvement of the species for solid wood production in the region.
- The targeted growing regions are those, which are slightly warmer than *E. grandis* growing areas including the coastal areas. However, the species can also be grown in *E. grandis* growing areas.

Breeding objectives: The primary market for *E. urophylla* is sawn timber. The main breeding objectives are fast growth, low splitting, good stem form, branching (angle and size) and tree health. Attention will be paid to stem breakage, to which this species is prone to in certain sites. Furthermore, selection for branching in this species is essential, as *E. urophylla* tends to have heavy branching, which is associated with larger DBH. Care will therefore be taken to adjust to this correlated effect and not select for smaller DBHs as a result. Research in the optimal spacing of *E. urophylla* with a view of minimizing stem breakage will also be initiated. The breeding strategy of *E. urophylla* is illustrated in Figure 2.

2.3.2.1 Current genetic resources

The genetic base is derived from 55 countrywide selections, which were planted as a seed stand in Muguga as well as newly imported 62 F1 families from Camcore (ex- Venezuela and Columbia) in 2019.

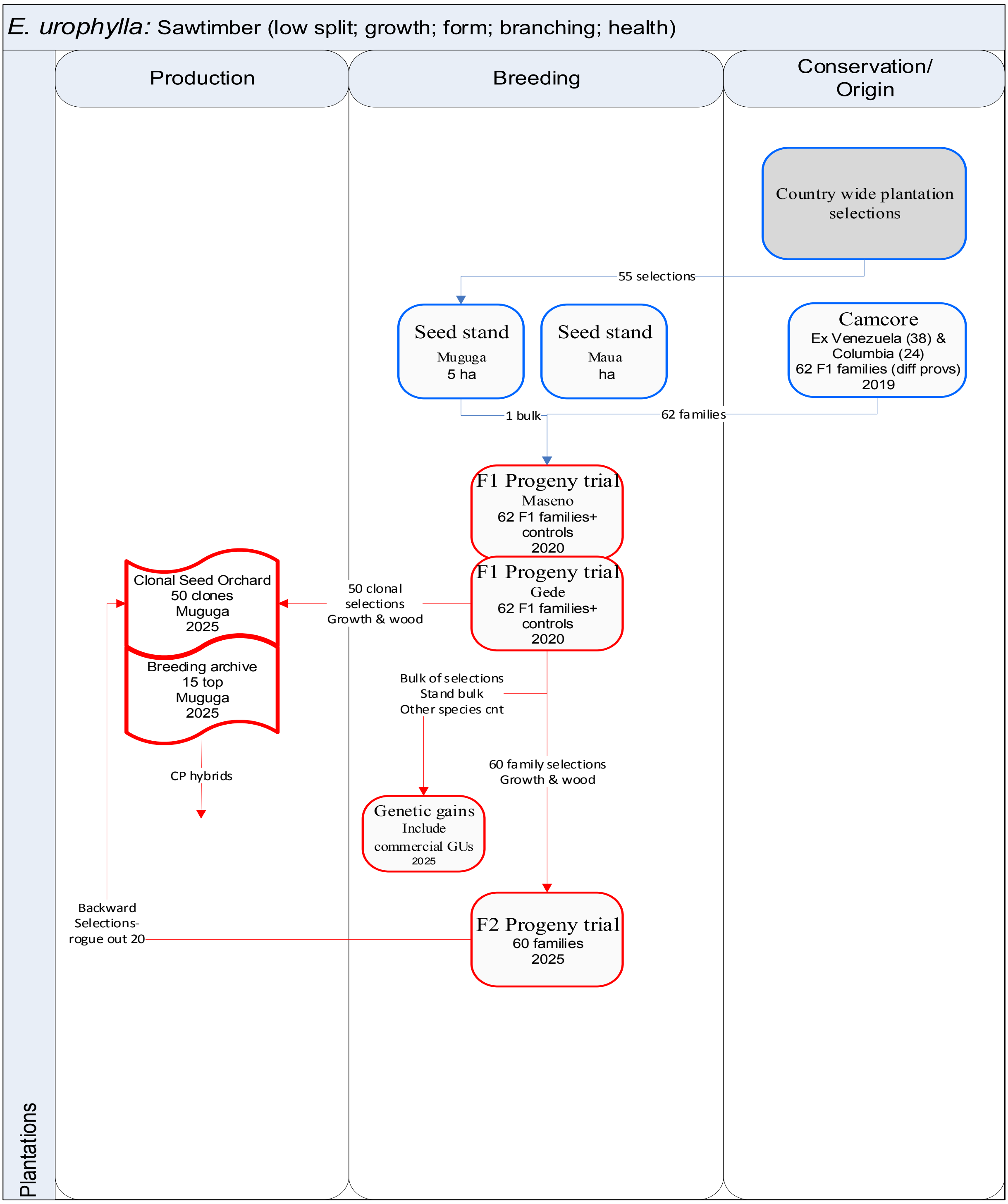

Figure 2: *Eucalyptus urophylla* breeding strategy in Kenya

2.3.2.2 Planned activities and interventions

1. The first priority is to establish a breeding population of 63 families including a control (F1 progeny trials) at Maseno and Gede in 2020.
2. Assess and analyze the progeny trials at age 4 and thin the poor individuals per family. Make first round selections based on the analysis.

3. Clear-fell the trial and assess the wood properties and collect the seed of the 80; 1st round selections. Collect grafts/coppice of the top 50 selections for a new clonal seed orchard to be established in Muguga in 2025. The top 15 elite selections will simultaneously be established in a breeding archive to be made available for a controlled crossing program
4. Open pollinated family seed of top 60 selections (after rejecting the 1st round selections with poor wood properties) will be placed in an F2 breeding population in 2025. This breeding population will also provide information to rogue the clonal seed orchard down to 30 clones in approximately 2028.
5. A genetic gains trial can be established in 2025 and can include un-improved seed from the seed stands, a bulk of seed from the F1 selection, commercial GU controls, E. *grandis* commercial seeds, etc.

2.3.2.3 Conclusions

Eucalyptus urophylla was identified as an important strategic species in the light of climate change and the needs of the country for an increase in the sawn timber resource. Although this species has not been bred before in Kenya, there is the opportunity to use 1st generation, improved material imported from the Camcore breeding programme, which will form the envisaged breeding base. This breeding base will be the source of selections for the clonal seed orchard and breeding archive in 2025. The team has identified that selection for solid wood properties will be a priority in this breeding population. The breeding archive will provide opportunities to develop new hybrids in the future.

2.4 Challenges to the Eucalyptus *breeding programme*

There are several challenges to tree improvement programme of *Eucalyptus* species, key among them are taxonomic differentiation, hybridization and zonation.

2.4.1 Taxonomic differentiation

To differentiate some species from each other requires high precision on characteristics i.e. *E. grandis* versus *E. saligna* and *E. camaldulensis* from *E. tereticornis*. Of late, it has been documented that *E. camaldulensis* is not a single taxon, but comprises seven subspecies (Butcher *et al.* 2009; MacDonald *et al.,* 2009 in Otieno, 2017) which are referred to as *acuta*, *arida, camaldulensis, minima, simulata, obtusa* and *refulgens*. They all have specific morphological variation and adaptation to specific niches within the species ecological range.

2.4.2 Hybridization

A number of Eucalyptus species hybridize spontaneously provided they grow adjacent to each other. For example, *Eucalyptus urophylla* can hybridize with *E. grandis* through controlled pollination or when grown side by side. These spontaneous hybrids confuse taxonomic identification as many varieties occur in between the two out-crossing species. These hybrids can be good material for enhancing productivity in forestry but they need to be identified and tested against parental material before they can be cloned for mass production. There are also several plantations of hybrids of *E. camaldulensis* and *E. grandis* (GCs) and *E. grandis* and *E. urophylla* (GUs) (Wamalwa *et al*. 2007), which must be kept at appropriate distance from the pure species' breeding populations to avoid unwanted back crosses.

2.4.3 Zonation

Various introduced *Eucalyptus* species can share ecological niches unlike in their natural origin where they are found and adapted to specific geographical areas. Therefore, the breeding programme must define ecological areas where specific species will be planted. It has also been observed in Kenya that *E. urophylla* will mainly prolifically produce seed when grown in high altitudes such as Muguga (KEFRI, 2004). However, E. *urophylla* performs best when grown for wood in areas along the Coast, Lower Meru, Tharaka-Nithi and along the Lake Victoria Basin.

2.4.4 Loss of selected candidate trees

Some of the selected plus trees were felled by landowners before cloning. There may be need to infuse further genetic material from other countries in order to enrich the genetic diversity of the breeding populations.

2.5 Further eucalyptus-breeding activities

Currently there are no sufficient breeding populations for *E. camadulensis* and *E. saligna*, however, the breeding strategies of these two species could be developed in future.

3.0 *Pines*

3.1 Background

Pines are fast growing exotic softwood tree species introduced to this country in early 1920's to provide raw material for the rapidly expanding wood based industry. Many pine species were introduced and planted in species site matching trials in the 1940s to determine their adaptability and growth patterns (McDonald, 1971). From these trials, *P. patula* and *P. radiata* were initially selected for large-scale planting due to their fast growth and their relative ease in establishment. However, *P. radiata* was subsequently discontinued from plantation establishment due to its susceptibility to *Dothistroma pinii* fungal disease. Currently, *Pinus patula* is the main pine species being planted on industrial scale and it grows best in areas where elevation ranges from 1500m to 3000m a.s.l, with rainfall above 1200mm.

Original introductions of *Pinus patula* into Kenya were from South Africa (Ex- Mexico). To-date *P. patula* is widely planted in high potential areas of Central Kenya and Rift Valley. It occupies up to 55% of industrial plantations in the country for supply of pulpwood, timber and plywood. Common planting espacement is 3 by 3m which leads to plant density of 1110 plants per hectare for the above management categories. The plantations are subsequently thinned to a final crop of 600, 356, and 250 stems per ha at ages 18, 30 and 35 years for pulpwood, timber and plywood respectively (KFD, 1981).

Pinus patula is described as fast growing. However, the early planting stock in Kenya achieved mean annual increment (MAI) of 1.48m for height between ages 10-20, whereas from 20-26 years, MAI in height drops to 0.61m (Ochieng, 1969). There was therefore need for genetic improvement of the species, in order to avail seeds and other planting material that would results in more productivity per unit area. Genetic improvement of *P. patula* aims at increasing biomass productivity per unit area as well as improving on quality traits to meet the needs of industry. The method has mainly been mass selection of superior mother trees (Plus Trees) from existing plantations and using them to establish clonal seed orchards (KEFRI 2018b). Progeny trials have been established to determine the genetic worth of the selected Plus Trees. The first selections of Plus Trees from commercial plantations were done in Kenya, Uganda and Tanzania in the 1960s and used to establish seed orchards in Muguga, Molo and Londiani. These plus trees were conserved in a clonal Tree Bank at Muguga and their seeds used to establish progeny trials. These early improvement work led to genetic gains of 10%, 5%, and 11% increase in height, diameter at breast height and volume production per hectare respectively (Obiri, 1992; Kariuki and Chagala, 2012).

Pinus patula hybridizes with other pines. In collaboration with Camcore, an international non-profit tree breeding organization, KEFRI has initiated a programme to import, hybridize and test the performance of such hybrids. To date, preliminary results indicate that hybrids of *P. patula* and *P. tecunumanii* at Muguga and Turbo are promising. New germplasm of *Pinus maximinoi* and *Pinus tecunumanii* are also showing good growth and adaptability in Turbo.

3.2 Breeding strategies of Pinus patula

Breeding objective: the primary market for Pinus patula is sawn timber, pulp and veneer. The breeding objectives for the species will be improved productivity, which encompasses fast growth, good form, light branching habit and pest and disease tolerance. *P. patula* will also be used as a main hybrid parent. The breeding strategy of *P. patula* is illustrated in Figure 3.

3.2.1 Current genetic resources

The origin of *P. patula* breeding populations can be traced back to selections from commercial plantations, which were established in Uganda, Tanzania and Kenya in 1960. The selections were used to establish F1 progeny trials and clonal tree bank in Muguga. These materials were used to establish seed orchards in Muguga, Molo and Londiani. New infusions were introduced from Zimbabwe in 2001, to broaden the genetic base of the species, and were used to establish seed stands in Londiani and Nyeri. Further selections were made from KFS commercial plantations, of which, 416 selections were used to establish series F1 progeny trials in Kamara between 2010 and 2013. Some of these selections from commercial KFS plantations were used to establish nine clonal seed orchards in Rift valley between 2005 and 2019.

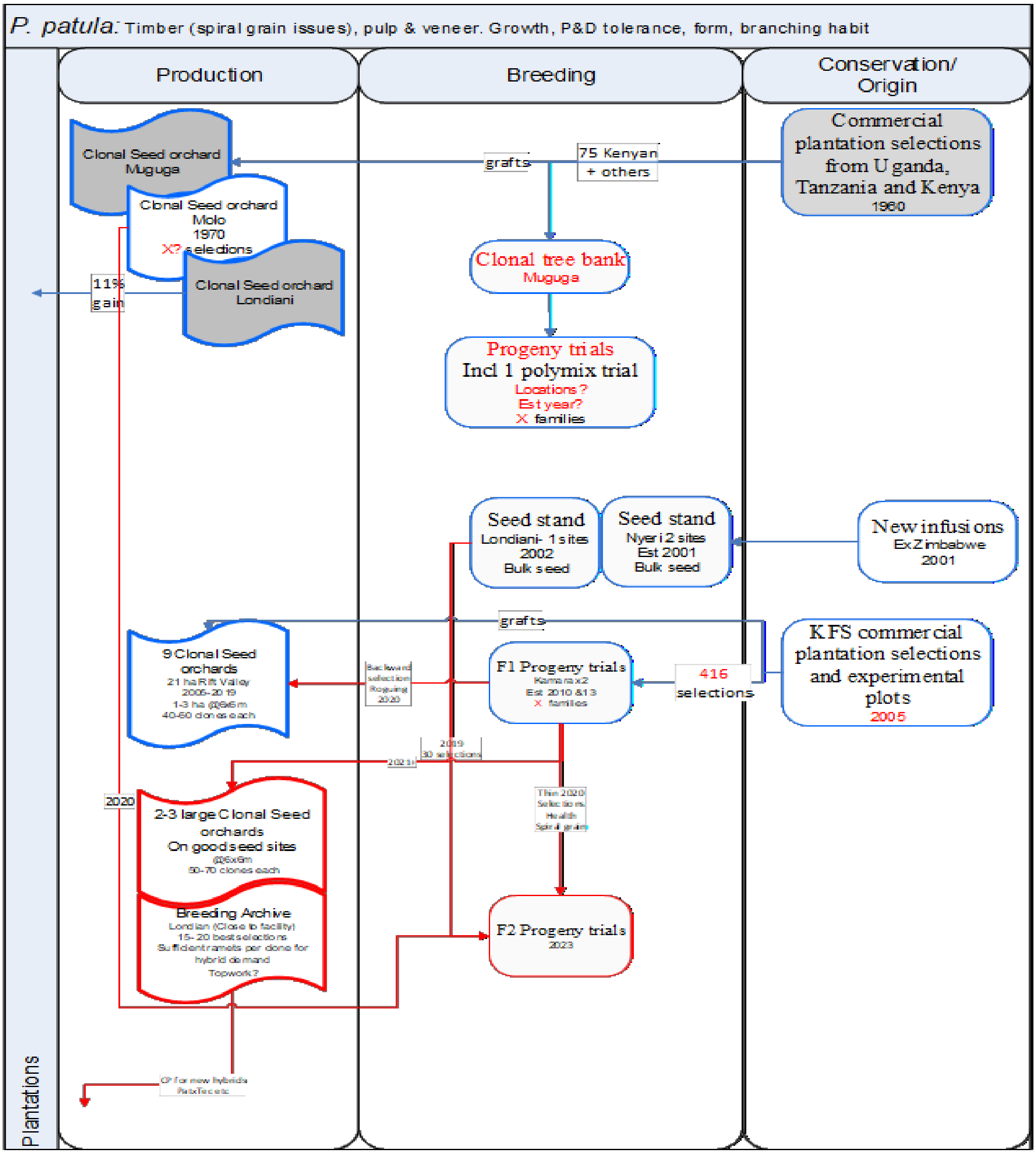

Figure 3: *Pinus patula* breeding strategy in Kenya

3.2.2 Planned activities

- Perform backward selection through analysis of the F1 progeny trials in Kamara and rogueing of the 10 clonal seed orchards in Londiani to improve the pollen cloud.
- The F1 progeny trials will be thinned in 2020 to enrich the pollen cloud. Seasonal pollination will be allowed and the seeds collected will be used for establishment of F2

progeny trial in 2021. In addition, Seeds will also be collected from the two clonal seed orchards (1967 and 1968) in Muguga for use in the establishment of the progeny trial.

- The analysis and thinning of the F1 progeny trial to provide high quality improved germplasm for establishment of F2 progeny trial.
- Establish a breeding archive to provide opportunities to develop new *P. patula* hybrids in the future.
- Develop two new large clonal seed orchards and enrich existing seed orchards through rogueing using the F1 progeny trial analysis.

4.0 *Cupressus lusitanica*

4.1 Background

Cupressus lusitanica (Mexican cypress) is native to Mexico. The species was introduced in Kenya in 1905 mainly from South Africa and France and has since become an important industrial and plantation crop in high elevation areas between 1500 to 3000 m above sea level. However, globally the species is found at elevations between 1000 to 4000 m above sea level (Orwa *et al*., 2009).

Intensive genetic improvement of *C. lusitanica* in Kenya started in early 1950s through selection of 74 superior mother trees in three registered seed areas. The selection was for rapid growth, light branching and resistance to Cypress Canker caused by *Monochaetia unicornis*. Open pollinated progeny trials were established in isolated areas to provide ranking for the mother trees. The trials were later converted to seed stands (Dyson, 1964). Seeds were collected from these selected superior trees and used in establishment of commercial plantations.

To broaden the genetic base of the species, new provenances were introduced in 1965 from New Zealand, Costa Rica, Mexico and Australia.

Another initiative involved selection of 102 superior individual trees in East Africa from which progeny trials were established. Thirty (30) superior trees were selected to establish two seed orchards in Muguga in 1967 and 1968 and these were later rogued for quality seed production. Generally, plantations raised from selected seed sources has led to improved performance with the crop attaining a mean height and diameter at breast height (dbh) of 12 m and 15 cm, respectively, compared to plantation established form general collections at 8.5

m of height and 12 cm dbh. The progeny trials' results show encouraging trends of heritability and genetic gains of key traits required in timber production. For example, heritability for diameter, height and volume is 0.89, 0.77 and 0.89, respectively, at 25 years while the genetic gain estimations is at 7%, 6% and 12% for height, diameter and volume/ha respectively. However, these figures are rather high and this maybe because provenance effect was not included in the analysis model.

Results from the previous genetic improvement programmes have shown that substantial gains were achieved through selection of superior (plus) trees for improved productivity of plantations and quality of products. Demand for improved cypress planting materials (seeds and seedlings) has been increasing hence the need for more seed orchards and genetic improvement of the germplasm.

4.2 Breeding strategy of Cupressus lusitanica

Breeding objective: the main market product for cypress is sawn timber. Therefore, the breeding objective is focused on selection for rapid growth, light branching and resistance to Cypress Canker. The breeding strategy for C. lusitanica is illustrated in Figure 4.

4.3 Current genetic resources

The *Cupressus lusitanica* in Kenya was originally from the imports from South Africa and France in 1905. However, intensive breeding of *C. lusiticanica* began in 1950, the selection of 74 families which were used to establish progeny trials. The seeds from the progeny trials were used to establish plantations. New infusions were brought in 1965 from Newzealand, Costa Rica, Mexico and Australia. In addition, 102 new selections from the East Africa land races were used to establish F1 progeny trials. From the F1 progeny trials analysis, 30 selections were undertaken and used to establish two clonal seed orchards, in Muguga in 1967 and 1968. Further new infusions were introduced to the breeding program through further selections 390 families from KFS plantations in Rift valley between 2004 and 2019. These selections were used to establish three F1 progeny trials in Kamara in 2006, 2008, 2013, and 10 clonal seed orchards.

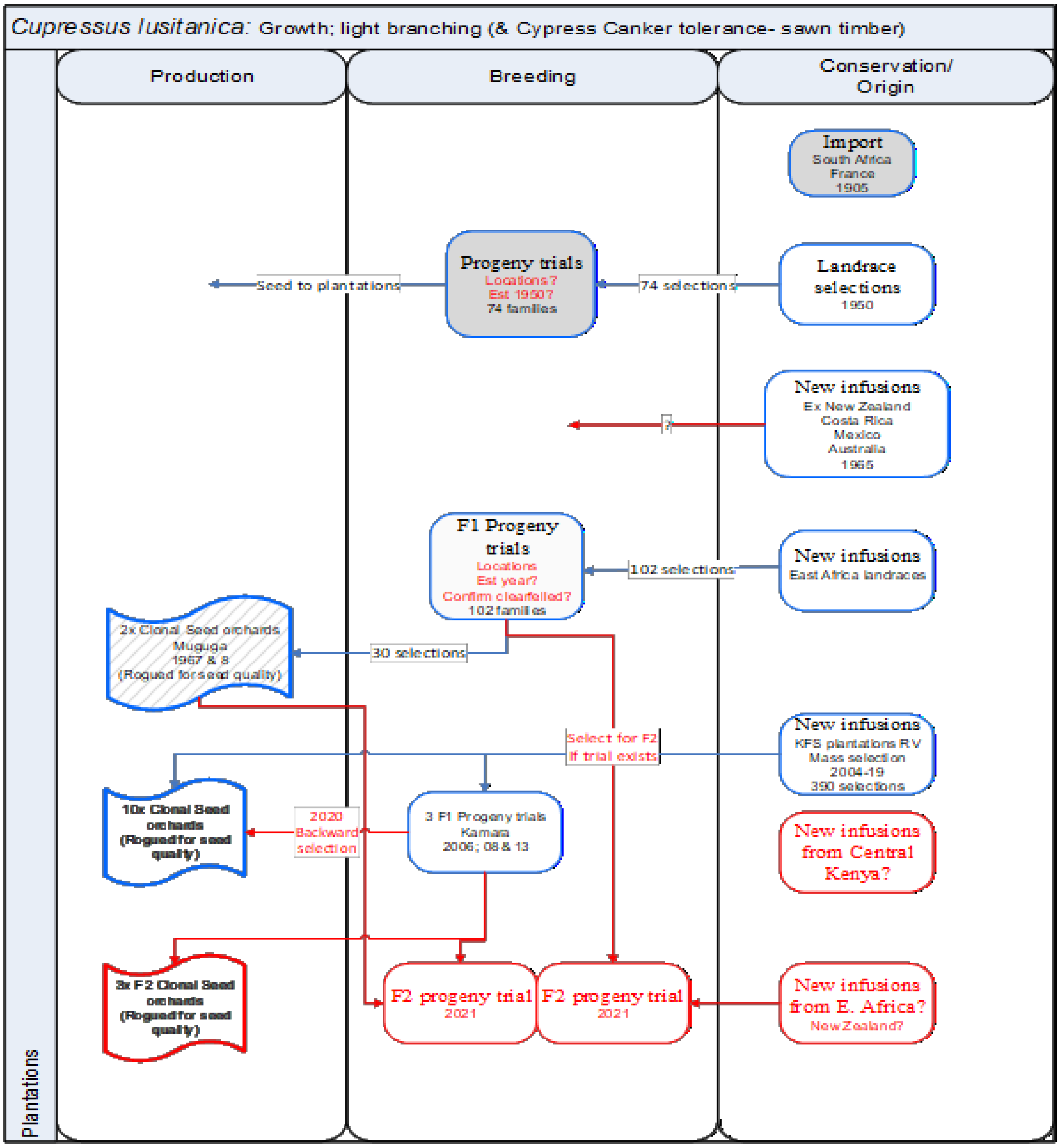

Figure 4: *Cupressus lusitanica* breeding strategy of in Kenya

5.0 Casuarina species

5.1 Background

Casuarina is a genus of 17 species in the family of Casuarinaceae, native to Australia, South Eastern Asia, and Islands of the western Pacific Ocean. The main species grown in Kenya are; *C. junghuhniana, C. cunninghamiana* and *C. equisetifolia*.

Casuarina equisetifolia is an evergreen; dioecious or monoecious tree 6- 35 m tall, with a finely branched crown (Rogers 1982). In Kenya, the species is widely grown along the coral beaches and nearby hinterland, but the species also grows well inland (Maundu and Tengnäs, 2005). The tree displays fast early growth under favorable conditions, and attains about 2 m/year in height with good form.

Casuarina junghuhniana is a fast-growing, deciduous tree native to Indonesia. It is a pioneer species of deforested land such as rocky slopes and disturbed sites. It is drought tolerant and can survive prolonged water logging. Trees are fire resistant when they attain a height above 2 meters and sprout readily on being damaged by fire (Kellman, 1986).

Casuarina cunninghamiana has some of the largest trees in the genus Casuarina, attaining a height of 20-35 m and diameter of 0.5- 1.5 m. It typically occurs in pure stands along freshwater streams and rivers, extending to adjacent valley flats and rarely hillsides. The tree is native to Australia and was introduced to Kenya for shelterbelts, erosion control and fuelwood.

Casuarina species are extensively cultivated for fuel, erosion control, and as a windbreak. The highly regarded wood ignites readily even when green, and ashes retain heat for long periods. It has been called ‘the best firewood in the world’ and also produces high-quality charcoal. *C equesitifolia* has a calorific value of wood of 5000 kcal/kg and that of the charcoal exceeds 7 000 kcal/kg, while *C. junghuniana* air-dry density of the wood is 900-1000 kg/cubic m, and the density of charcoal is 650 kg/cubic m(El-Lakany *et al.,* 1991). The energy from the *C. junghuniana* charcoal is 34 500 kJ/kg, which is among the highest among firewood species. It has been used for both domestic and industrial fuel such as for railroad locomotives.

C. equisitifolia provides other services such as soil erosion control since it is salt tolerant and grows in sand, it is ideal for use in controlling erosion along coastlines, estuaries, riverbanks and waterways. In southern part of China, an estimated 1million hectares has been established in shelterbelts along the coastal dunes. It is also the best species for land reclamation as it grows on barren polluted sites and thrives in deep sandy soils. *C. equisetifolia* may be the only woody species growing over a ground cover of dune grasses and salt-tolerant broadleaved herbs; it can also be part of a richer association of trees and shrubs collectively termed the Indo-Pacific strand flora. In Kenya, it grows around cement works, in Hawaii in sterile pumice, in Malaysia on sterile tin tailings, near Hilo Bay on tidal rocks with its roots in salt water (NAS, 1983e).

C. equisitifolia and *C. junghuhniana* play a major role in nitrogen fixing and soil improvement. Root nodules containing the actinorhizal symbiont Frankia enable *C. equisetifolia* to fix atmospheric nitrogen. These root nodules can be prolific. The tree also possesses proteoid roots and forms associations with vesicular arbuscular mycorrhizae, hence improving the soil (Wang and Qiu 2006). With high productivity and properties that enhance soil fertility, *C. equisetifolia* shows promise as an agroforestry species for arid and semi-arid areas (Diem et al. 2000). Experiments at Prabhunagar, India, showed citrus trees grew larger under *C. equisetifolia* than in pure stands.

5.2 Current breeding status

Despite the numerous uses of the species, tree improvement work on *Casuarina* species in Kenya is limited to initial provenance trials across several sites in the country. *Casuarina equiesitifolia* trials were established in Gede as part of a series of international provenance trials while *C. junghuhniana* trials were planted in Uplands and Kiandogoro in 1997. However, the information on data collection and the progress of the experiments is missing.

5.3 Planned activities

- Undertake a review on the potential of this species
- Introduce more germplasm to initiate a breeding program
- Develop a breeding strategy with breeding objectives

6.0 *Melia volkensii*

6.1 Background

Melia volkensii, locally known as Mukau or commonly as Melia, is an important endemic and highly valued tree species growing in the arid and semi-arid lands (ASALs) of Eastern Africa with geographical distribution in Ethiopia, Kenya, Somalia and Tanzania. In Kenya, it is naturally found in the arid and semi-arid regions within agro-ecological zones IV-VI. The tree is valued for its high quality timber, which it yields in a short rotation of 10 – 15 years, thus considerably fast growing compared to other hardwood trees. These qualities, combined with low tree-crop competition when properly managed, have made Melia a popular species in the drylands where farmers have intercropped the tree with agricultural crops for years. In the natural stands, however, *M. volkensii* has been heavily exploited for timber and most trees are now found on farms.

Kenya Forestry Research Institute (KEFRI) has undertaken research on *M. volkensii* since early 1980s leading to major breakthroughs in the species' propagation, innovation of nut cracker to improve seed extraction, and in tree establishment. Some of the early research involved pilot plantations in 16 farmers' fields, which revealed high levels of diversity among the Melia tree crops. This probably led to the slow uptake of Melia investment despite impressive prediction on socio economic returns (Wekesa *et al*., 2012). To address the concerns of low uptake, in 2004 KEFRI organized a first national workshop on Melia at Kitui regional research centre to take stock of research breakthroughs, research and development gaps and to prioritize issues raised by stakeholders (Kamondo *et al*., 2006). During that first national workshop, *M. volkensii* was prioritized as a timber species.

In 2008, KEFRI with support from Japanese International Cooperation Agency (JICA) under the project on 'Development of Drought Tolerant Trees for Adaptation to Climate Change in Drylands of Kenya' developed a Melia breeding strategy that constituted, among others, selection of Plus trees and establishment of progeny trials and seed orchards using the selected material. The breeding objective was production of fast growing trees for timber production that will be drought tolerant and adaptable to both the common Melia growing areas and drier sites.

6.2 Breeding strategy of Melia volkensii

Breeding objective: Develop fast growing and healthy trees for timber production that will be drought tolerant and adaptable to both the common *Melia volkensi* growing areas (ecological zones IV and V) and more extreme arid areas (zone VI). The breeding strategy of *M. volkensii* is as illustrated in Figure 5.

6.3 Current genetic resources

Eighty plus trees were selected in arid and semi arid areas, (Mutha-Inyali, Katulani-Kavisuni, Voi-Mwatate, Voi-Galana, Embu-Ishiara-Gatunga, Embu-Dams, Mwea Special, Mwingi-Nuu, Mwingi-Tseikuru, Isiolo-Meru, Garissa-Bangale, Garba-Wamba and Wamba-Marsabit) and 20 in very arid natural conditions(Garissa, Wamba, Garbatulla and Marsabit). These materials were used to establish two large clonal (each 11 ha) seed orchards in Kitui and

Kibwezi between 2012 and 2014. In addition, these materials were also used to establish 8-F1 progeny trial series; Four main progeny tests located at Kitui, Kibwezi, Marimanti and Kasigau and 4 sub-progeny tests at Makima, Gaciongo, Ikithuki and Voi were established in 2014 and 2015, representing sites of Melia's occurrence range in Kenya.

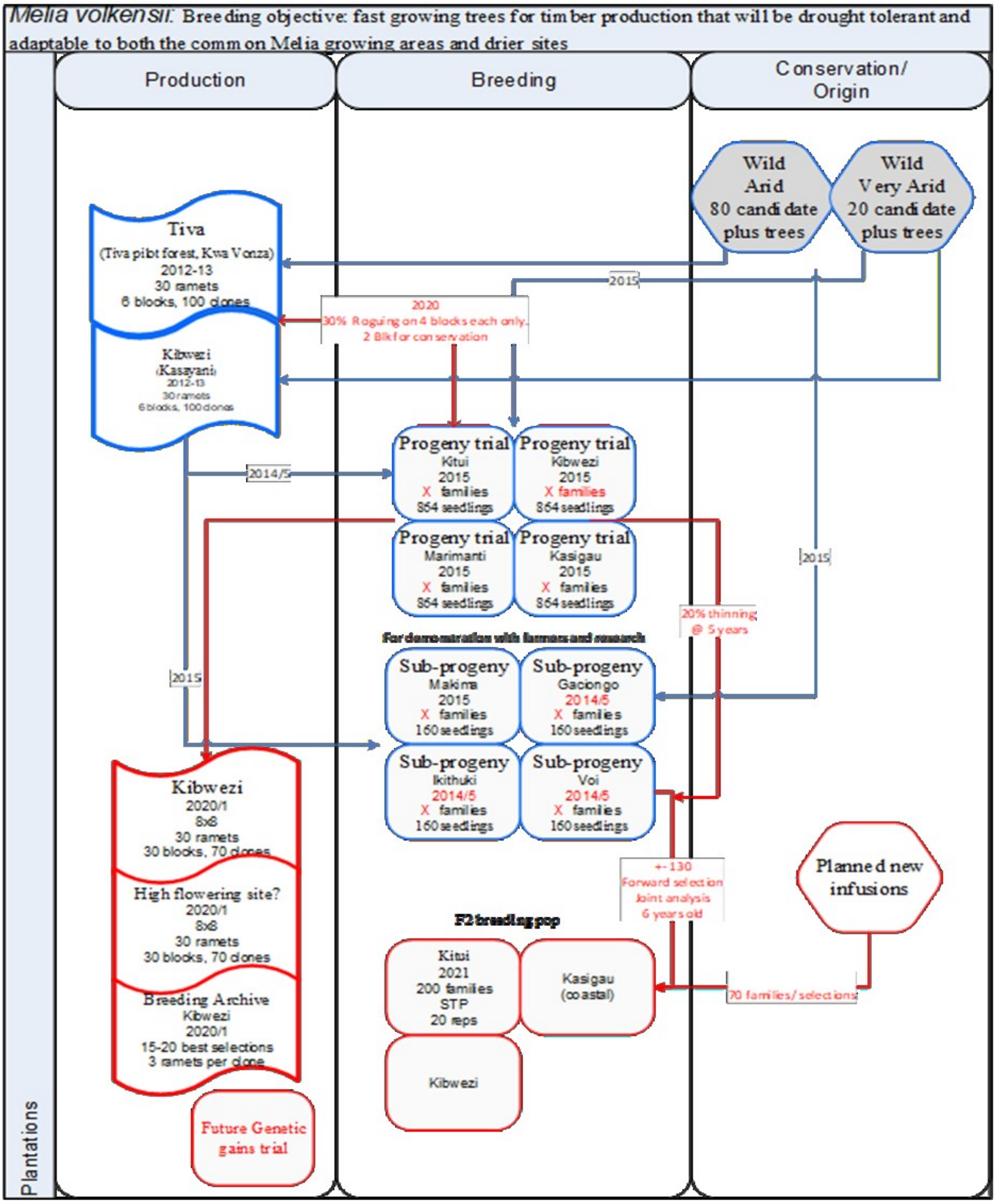

Figure 5: *Melia volkensii* breeding strategy in Kenya

6.4 *Planned activities and interventions*

1. Improve the existing seed orchard through a 30 percent rogueing of 4 of the 6 blocks, based on the progeny performance observed in the series of progeny trials. This is because the two of the six blocks will be left as a breeding archive for all the selected material. This is planned for execution in 2020.
2. Joint analysis of the 2015 main progeny and sub progeny trials. The results from this analysis to be used to identify the next series of clonal seed orchards and a breeding archive in 2020/21. The best non-related 70 individuals will be cloned for the seed orchard and the top non-related 15-20 for the breeding archive. In addition, 130 forward selections will be identified for the F2 breeding population.
3. The progeny and sub progeny trials will undergo 20 percent thinning per family at the age of 5 years in order to enrich pollen cloud. The purpose of this action is to prepare the trials for production of improved next generation seed (F2 seed).
4. Collect seeds from the 130 forward selections at age 6 to form the F2 breeding population.
5. An additional 70 selections to be made and infused into the population in 2021. The proportion of the arid/semi arid/very arid selections should be informed by the analysis of the progeny trials. If families from one particular zone are proving to be superior to another then emphasis should be placed on collection from that zone. It has been identified that valuable genetic diversity may exist in the extremes of the natural distribution of this species and collections from these extremities (southern Ethiopia and northern Tanzania) should be included in the new infusions. The next breeding population ("F2") will be the combination of the 130 forward selections plus the 70 new infusions to bring the total population to 200 families.
6. Establish genetic gains trials in order to monitor the relative improvement of the various seed sources. Potential entries in the genetic gains trials include a bulk from each of the current 2012/13 seed orchards; bulk from the same orchards after rogueing, bulks from the orchards arranged according to zone origin, a bulk of the F2 seed collected from the progeny trials and a bulk from the new infusion seed.

7.0 *Grevillea robusta*

7.1 Background

Grevillea robusta (silky oak) from the family Proteaceae is a tree species with limited natural distribution in the subtropical and warm temperate eastern Australia (Harwood & Booth, 1992). The species occurs naturally in two distinct habitats; the Araucaria dominated vine forest and the alluvial flats along rivers and streams on various soil types. The species occurs naturally from the sea level to 1100m. It was introduced in other countries in the 19th century and is currently widely planted in the subtropical and the tropical highland areas in Asia, Africa and America. The economic uses of this tree have evolved over time as it was initially used as shade tree for coffee and tea and in the recent past as an important agroforestry tree species used for row and boundary planting, sawn timber, poles, firewood and leaf mulch.

G. robusta was introduced to Kenya from Sri Lanka in about 1901 in association with *Acacia mollisima, A. decurens*, pines and eucalyptus, and by 1920 it had been widely planted on farms. The current stock of the tree species in Kenya came from a very narrow genetic base (Harwood, 1989), which is a situation that is not favorable in case of pest outbreak as was experienced in Puerto Rico where the attack by Pastule scale resulted in considerable reduction in the area under *G. robusta* (Koscinski, 1939).

In 1989, the international Council for research in Agroforestry (ICRAF) in collaboration with KEFRI included Grevillea among the four-agroforestry tree species selected for intensive programmes of genetic improvement for use in agroforestry systems in east and central Africa including Kenya. In Kenya, the tree performs well in areas receiving rainfall ranging from 1525 to 2030mm (Herlocker et al., 1980). The tree grows well in well-drained soils at an altitude of 1221-2289m above the sea level (Milimo, 1988). The highest concentration of this tree species is in the central highlands around Mt. Kenya and the Aberdare ranges in the counties of Muranga, Kirinyaga, Embu, Meru, Nyeri, Laikipia and Nakuru.

7.2 Current breeding status

In 1999-2000, KEFRI initiated development of improved seed sources of *G. robusta* through conversion of progeny trials established jointly with ICRAF in 1989 by thinning of the 3 ha existing at Kakamega, Kodera and Ramogi.

A total of 236 candidate plus trees were selected from progeny trials in Malava (24), Kakamega (55), Kodera (45), Ramogi (105), and Muguga (7). Currently 17 ha of clonal seed orchard have been established in various sites in Kenya as follows: 5 ha in Turbo, 4 ha in Nyatike, 2 ha in Njukini, 2 ha in Nyambene, 2 ha in Murang'a and 1 ha in Nanyuki. The initial orchards were established in Ramogi and Kuja River but these dried from drought. A tree bank also exists in Muguga.

7.3 Planned activities

The following are recommended as actions for the way forward:

- Formulate the key objectives of genetic improvement aligned to the national needs
- Develop a breeding programme with the breeding objectives
- Establish progeny trials to develop an advanced (F2) generation breeding population and to evaluate the candidate plus trees and to enable roguing of the seed orchards
- Monitor the genetic gains/ improvement from the program

8.0 Gap analysis

Table 1. Gaps and mitigation measures for commercial tree breeding programme

Genus/Species	Identified gaps	Mitigation measures
Eucalypts	• Taxonomic differentiation • Spontaneous hybridization • Inadequate information to guide the appropriate zonation for various introduced Eucalyptus species and hybrids • Loss of selected candidate trees • Insufficient breeding populations for *E. camadulensis* and *E. saligna*	• Develop and establish a robust and accurate taxonomic differentiation of Eucalyptus species • Ensure that plantations of hybrids such GxC and GxU are kept at appropriate distance from the pure species' breeding populations. • Carry out provenance and species trials to inform the suitable zonation Eucalyptus species and hybrids • Infuse further genetic material from other countries in order to enrich the genetic diversity of the breeding populations. • Develop breeding strategies for *E. camadulensis* and *E. saligna*

Genus/Species	Identified gaps	Mitigation measures
Pines	• Inadequate information and data on the progeny trials to guide management of orchards and further progression of breeding • Inadequate genetic base for the potential species such as *Pinus maximinoi* and *Pinus tecunumanii* to support breeding programme	• Analysis and selection from the the F1 progeny trials of about 30 families • Establish two large clonal seed orchard in 2021 probably in either Londiani or Muguga • Undertake backward selection form the results of the F1 progeny trial through rogueing of the 9 clonal seed orchards in Londiani. • Establishment of F2 progeny trial in 2023 from the F1. • Establish a breeding archive of between 15 to 20 best individual selections in Londiani for hybridization research work. • Undertake controlled pollination of new hybrids of *P. patula* and *P.technumanii* and possibly *P. maximinoi*.
Cupressus lusitanica	• Inadequate information and data to guide management of orchards and further progression of breeding • Inadequate genetic base for *C. lusitanica* to support breeding programme	• Generate information and data to guide management of orchards and further progression of breeding • Obtain new infusions through further selections from Central Kenya and importation from countries such as Newzealand to broaden the genetic base.

Genus/Species	**Identified gaps**	**Mitigation measures**
Casuarina equisetifolia	• No breeding programme • Inadequate information on current and potential alternative uses	• Establish a breeding program for *Casurina equisetiflia* • Obtain new infusions from India and other South east Asian Countries to broaden the genetic base Infuse
Melia volkensii	• KEFRI unable to meet the high demand for improved Melia seed • Melia breeding program based on 100 families • Funding constraints for Melia breeding programme	• Move the breeding population forward to an F2 generation by thinning and selection • Broaden genetic base to 200 families through the introduction of new infusions • Establish a sustainable breeding fund and plough back some funds from sale of improved seed
Grevillea robusta	• Lack of a systematic breeding programme for *Grevillea robusta* • The 236 candidate plus trees have not been evaluated	• A systematic breeding programme for *Grevillea robusta* • The 236 candidate plus trees have not been evaluated

9.0 Overall conclusion and way forward

Tree breeding is key to improved productivity of forest plantations. Based on the present review, the major commercial plantation tree species in Kenya have undergone various levels of improvement and there exist sufficient breeding populations for five species that will be moved to advance breeding levels. In this regard, tree improvement strategies have been formulated for the 5 priority species namely *Eucalyptus grandis*, *Eucalyptus urophylla*, *P. patula*, *C. lusitanica* and *M. volkensii.* Each of the priority species has clear, focused, breeding objectives aligned to national needs, which will be implemented at varying levels of intensity depending on the available genetic resources. However, for *G. robusta*, *Casuarina equisitifolia*, and *Casuarina junghuhniana,* review of the available breeding populations is recommended before drawing breeding strategies for the species. It is however important to:

- Verify and inventorize existing seed sources, trials and selected plus trees and define appropriate high-potential production sites for the future;
- Establish and manage few, large seed orchards in replicated sites;
- Assess the genetic diversity and associated risks and the need for new infusions;
- Select new candidate plus trees for advancing the level of improvement of the breeding objectives, to a new and improved generation
- Develop intra and inter-specific hybrids where the opportunity arises
- Develop clonal multiplication techniques for mass production of the best material
- Establish species, provenance, progeny and clonal trials where appropriate; and conduct wood quality studies where necessary
- Monitor the genetic gains and improvement from the programmes
- Develop and revise silvicultural management techniques for various species