Norway's International Climate and Forest Initiative (NICFI)

Breeding plans of *Eucalyptus globulus* and *Afrocarpus falcatus* for Ethiopia

Consultancy Report

September 2019

TECHNICAL

Provision of Adequate Tree Seed Portfolios:
Establishment of Breeding Seedling Orchards for indigenous Fruit Trees

Breeding plans of *Eucalyptus globulus* and *Afrocarpus falcatus* for Ethiopia

Consultancy Report
September 2019

Antoine Kalinganire, PhD
Senior Tree Scientist, World Agroforestry Centre (ICRAF-WCA/Sahel), Bamako, Mali

A.Kalinganire@cgiar.org

Table of Contents

Acronyms

ARARI: Amhara Agricultural Research Institute - Ethiopian Agricultural Research Directorate

BCO: Breeding Clonal Orchard

BSO: Breeding Seedling Orchard

EEFRI: Ethiopia Environment and Forest Research Institute

FRC: Forestry Research Center

ICRAF: World Agroforestry

IUCN: International Union for Conservation of Nature and Natural Resources

MEFCC: Ministry of Environment, Forest and Climate Change

NICFI: Norwegian International Climate and Forest Initiative

PATSPO: Provision of Adequate Tree Seed Portfolios

SNNPR: Southern Nations, Nationalities and Peoples' Region

SPA: Seed Production Areas

STL: Senior Team Leader

TARI: Tigray Agricultural Research Institute

1. Generalities

1.1 Activities and Expected deliverables from the consultancy

The primary purpose of the consultancy is to:

a) Follow up on work from previously visits to PATSPO related to collaboration on mother block establishment of fruit trees (Baobab, Ziziphus and Tamarind) in Ethiopia, and;

b) Finalise the detailed forward-looking breeding plans on *Eucalyptus globulus* and *Afrocarpus falcatus.*

Specific tasks during the stay in Ethiopia are:

- Prepare breeding programme for 1-3 of the priority tree species of Ethiopia.
- Visit the Sirinka and Kobo sites and assess the status of the established mother blocks and farmer plantings.
- Provide training on grafting techniques for nursery staff and farmers involved in the mother block activities at Sirinka and Kobo.
- Suggest follow up activities to the ongoing work in Sirinka and Kobo. Action points and recommendations are detailed in section 6.
- Prepare the report and note described under section four above.

Two major outputs should be produced:
A note describing the status of the mother block establishment of fruit trees (Baobab, Ziziphus and Tamarind) in Sirinka and Kobo, including training provided during the visit to the site, as well as suggestions for follow up activities to the ongoing work.

Detailed breeding programmes for the two species *Eucalyptus globulus* and *Afrocarpus falcatus* based on and linking to the earlier breeding work done in Ethiopia and the PATSPO BSO programme.

This report covers the breeding programmes for *Eucalyptus globulus* and *Afrocarpus falcatus* based on and linking to the earlier breeding work. The report on the status of introduced three indigenous fruit tree species namely *Adansonia digitata* (baobab), *Tamarindus indica* (tamarind) and *Ziziphus mauritiana* (ziziphus or jujube) was given in a separate report. Activities were covered during this field trip done by the Consultant from 22nd April to 17th May 2019 (see details in *Appendix 1*), and during another field trip from 18 November to 3 December 2018. The latter trip was reported in January and briefly in section 1 as background information to this report.

1.2 Purpose and background of the consultancy

The aim of PATSPO is to design a breeding programme for more than 50 priority species and to establish breeding seedling orchards (BSOs) and other types of mother blocs for a sub-set of these species. Further background information is available in the Project Document and references therein which should be consulted. The Terms of Reference for this consultancy are

given in Appendix 1. Travel itinerary, activity and people met are given in Appendices 2 & 3 respectively.

The establishment of BSOs for tree breeding and seed procurement is an important activity of PATSPO. Ethiopia has been and are at present engaged in many tree improvement/ breeding and seed stand programmes/activities. Some of the older field establishments are not maintained and therefore questionable for use in ongoing and future breeding programmes, however some field establishments can be used, if some urgent maintenance is done. The consultant further finalised the detailed forward-looking breeding plans on *Eucalyptus globulus* and *Afrocarpus falcatus*. A detailed plan for what genetic material to include in the breeding plans is given.

2. Methodology

The consultant assessed at how the results of earlier and ongoing tree improvement activities are linked with the PATSPO BSO programme and be used in forward looking tree breeding activities in Ethiopia.

The country has been and are at present engaged in many tree improvement/breeding and seed stand programmes/activities. A review of the status of previous and on-going work on tree breeding and a report has been provided: Status of tree improvement and gene conservation in Ethiopia (Tadesse, 2018).

The report has been consulted and is a partial basis of this activity. Based on Wubalem Tadesse (2018) report (a desk review), a literature review (full list to be provided in the final report), from the consultation of PATSPO staff members, and scientists from the Ethiopian Environment and Forest Research Institute (EEFRI), from the Forestry Research Center (FRC). Moreover, field trips and from my previous Ethiopian experience, priority species and their respective breeding plans have been developed in this report.

3. Expected outputs - facts and results from the assessments

3.1 Status of previous and ongoing tree improvement programmes in Ethiopia

Discussions under this section are the results of my consultancy in Ethiopia from 18 November to 3 December 2018 (refer to the Consultancy Notes of January 2019). During the period, I covered the assessment of the use of the PATSPO consultancy report on status of previous and ongoing tree improvement programmes in Ethiopia (Tadesse, 2018), a field visit to some selected tree breeding field establishment of key tree species in Ethiopia plantations, and

several meetings with PATSPO resource technical staff, under the guidance from the Senior Team Leader (STL), Mr. Soren Moestrup. The outcomes hereunder summarized are key to the breeding plans of key tree species in the country.

Ethiopia has been and are at present engaged in many tree improvement/breeding and seed stand programmes/activities. PASTPO has convened a review of the status of previous and on-going work on tree breeding and a report has been provided: Status of tree improvement and gene conservation in Ethiopia (Tadesse 2018). The report has been a basis of this activity. Based

on the report (a desk review), a literature review (full list to be provided in the final report), from the consultation of PATSPO staff members, and scientists from the Ethiopian Environment and Forest Research Institute (EEFRI), from the Forestry Research Center (FRC); from the field trip and from my previous Ethiopian experience, key findings (mainly for key priority species) are developed and reported.

Wubalem Tadesse was based on other reports without any consistent field inspection. Some of the information on the status of existing trials on major tree species may be erroneous and would require further review. Therefore, the results are not much reliable, examples include the management status the some of the seed productions areas, seed production estimates, the genetic composition of the stands including species identification. Most tree species, both indigenous and exotics, were introduced and/or planted in Ethiopia. The original introductions or plantations and many additional imports of planting materials were poorly documented as their exact identity and origin are therefore not known (ref. to my 2018 field trip, interviews with A. Dorero (FRC)). Their genetic history is therefore obscure, and problems are beginning to arise with inbreeding depression and extreme growth variation in some progenies, e.g. in *Eucalyptus grandis* SPA (Yergalem, Hawassa), *E. camaldulensis* insect attacks (Dorero, pers. information) and poor performance in some areas in the lowlands/drylands.

Regarding the adaptations/species introduction trials for exotic species, provenances and progeny trials need to be dealt with precautions as discussed (non-existing or doubtful designs, unknown origins and genetic compositions of such plantings) for any further use in the on-going tree improvement programme. Notwithstanding further investigations, e.g. number of trees in the original collection for the plantation) as per the reports and scientific publications the following trials may be useful for further research:

- Provenance/progeny trials of *Eucalyptus globulus* (Ilalaa Gojo), *E. grandis* (Wondo Genet), *E. saligna* (Hunde et al.) may be used in further improvement work. Individual selections based on the best provenances, maximum of one tree per progeny, may be collected for the on-going BSO program. However, their management into SPAs is doubtful, especially based on earlier designs of such trials (to be developed further into the reports).
- *Grevillea robusta* SPAs (Yergalem, Bedele, Wondo Genet etc), seems to have originated from Nimbin, Australia (Derero, pers. information). Nimbin was not the best provenance in growth in other similar environments (Kalinganire and Hall, 1993; Kalinganire and Zuercher, 1990), but showed interesting growth in Ethiopian conditions. SPAs have been poorly managed for seed productions (high density, small crowns with small branches etc). Plantations are good for timber, and few plus-trees (e.g. 1/100 trees) may be selected and added into the evolving new established BSOs.
- Exotic softwoods plantations, including *Cupressus lusitanica, Pinus patula, P. kesiya, P. tecunumanii* etc., are also important. For *Cupressus lusitanica*, interesting plantations with exceptional performance have been seen in Wondo Genet, and in the highlands of Monessa – Yebenercy Forest. However, it is not clear on the origins of such plantations. Converting to, and managing them as SPAs would be risky with unknown genetic composition of the

parent materials. The on-going BSO program can select few individuals (high selection intensity) and have them included in the on-going BSO for the species.

- Tree improvement work with indigenous tree species is very basic for any useful information. *Afrocarpus falcatus* plantings in Yergalem shows good performance. Planted in 1995 (not sure as few stories around the history of that plantation), to-date it accuses poor fruiting. Origins of seed is claimed (but to be confirmed), from Addis Alem (near Holleta). The plantation may be thinned with inferior trees and be managed for seed production. Individual plus-tree selection (maximum of five trees) from the site may collected for the planned BSOs.

Most of the older field establishments are not maintained and therefore questionable for use in ongoing and future breeding programmes, however some field establishments can be used, if some urgent maintenance is done – but most may need further investigations to understand their further benefits from such investments on for seed production. Such study would assess seed production (quantity, physiological and genetic quality), site protection and any further investment needed for the SPA (e.g. sylvicultural operations to improve the stand such as thinning, pruning etc). The result would be compared to the cost of establishing a new SPA/BSO with populations of higher broad genetic base.

Regarding the on-going national tree improvement work, as per Wubalem Tadesse's report, EEFRI conducts tree improvement, seed sources establishment and seed procurement programs. However, the same problems persist, no genetic composition and experimental designs for such trials. Thus, the quality of seed supplied by EEFRI, from trial areas, is doubtful and not credible for use in the on-going reforestation programs. From the discussions, it is recommended that:

- Collection of seed for the establishment of BSOs, individual plus-trees should be identified and collected from trials of known origins (and of the best provenances) and included in the evolving BSOs.
- New BSOs should be established at locations where heavy flowering and seed production of the species is observed. Moreover, large spacing and/or early heavy thinning, are recommended for trees to develop heavy branches for fruiting/seed production.
- Training of EEFRI and forest enterprise technical staff in BSO management for the future of BSOs program in Ethiopia, including records keeping, tree management for seed production and key observations to be organised by the end of the program.
- Encourage and support the assessment, analysis, evaluation and publication of the existing provenance/progeny trials for most of the species, and help with a national tree breeding strategy for Ethiopia.

3.2 Selection of key priority tree species and establish breeding plans

Eucalypts were introduced to Ethiopia more than a century ago. As discussed above, it is certain that the original introductions at the end of the 19th Century consisted of small quantities of seed of a few individuals, probably collected from elsewhere in Africa, the Mediterranean or Iberian Peninsula rather than directly from Australia.

As reported by Davidson (1995) and Wubalem Tadesse (FRC), Abayney Dorero (FRC) and Yigardu Mulatu Mengesha (EEFRI) (personal communications), the most popular and widely planted species in Ethiopia are *E. globulus* (highlands), *E. camaldulensis* (lowlands and drylands) and *Grevillea robusta* on-farms. Other important exotic species include *E. grandis*, *E. tereticornis*, *E. saligna* and *E. urophylla*, as well as *Acacia mangium, A. decurrens (A. mearnsii), Cordia africana, C. alliodora, Cedrela odorata, Gmelina arborea, Hagenia abyssinica*. For commercial plantations, Eucalypts, *Pinus patula* and *Cupressus lusitanica* are dominant. For indigenous species and on-farms plantings few are planted including *Juniperus procera*, *Cordia africana* and *Afrocarpus falcatus*.

Regarding tree priotization of species for the BSO establishment, PATSPO made a recent survey though key partners including CEE-FRC, SNNPR, Oromia, Amhara and Tigray regions – with more than 10 key-respondents from 7 institutions, the following species have been proposed as high priority: *Hagenia abyssinica, Juniperus procera, Afrocarpus falcatus, Cupressus lusitanica, Faidherbia albida* and *E. globulus* ssp. *globulus*. Thus, from the survey the next proposed tree species for BSOs with detailed breeding programs are: *Eucalyptus globulus* spp. *globulus* and *Afrocarpus falcatus* (syn. *Podocarpus falcaltus, P. usambarensis, P. gracilior*).

The report is divided into two main parts. The first part discusses about the breeding plan of *E. globulus* spp. *globulus* and the second on the breeding plan of *A. falcatus*. Each part summarizes for each species the current breeding work undertaken in Ethiopia, a breeding strategy and a time plan for operations during the first generation and some recommendations for future work.

4.Breeding plan of *Eucalyptus globulus* subsp. *globulus*

4.1 General introduction and biology of the species

The species in Ethiopia - Provision of Adequate Tree Seed Portfolios (PATSPO) to enhance productivity and resilience of Forest Landscape Restoration in Ethiopia is a project supported by a grant from the Government of Norway through the Norwegian International Climate and Forest Initiative (NICFI).

PATSPO is designed to support Ethiopia in its ambitious programmes of forest landscape restoration with a commitment to restore more than 20 million ha of degraded forest landscapes within the next 20 years. A major challenge of forest landscape restoration work is that it generally requires the use of planting material in large quantities of a broad spectrum of genetically diverse, healthy and productive tree species.

Current planting programmes in Ethiopia are dominated by very few species of which Eucalyptus is the prominent. Over-reliance on a few species in large-scale restoration is risky and in the future use of a more diverse set of species is considered necessary to provide for both economic and ecological resilience. The aim of PATSPO is to design a breeding programme for more than 50 priority species and to establish breeding seedling orchards (BSOs) and other types of mother blocs for a sub-set of these species.

Eucalyptus globulus ssp. *globulus* is one of the key species used in the Ethiopian reforestation program. *E. globulus* has proved extremely well adapted and is performing well in Ethiopia. *Eucalyptus globulus* was imported to Ethiopia in 1894-1895 (Pohjonen and Pukkala 1990). The species was one of the first introduced species in Ethiopia and is the most popular to an extent that it is considered indigenous by the local communities. Locally it is known as 'Bahar Zaf' – tree which came from beyond the seas. The species is mostly planted around Addis Ababa and in the Central Highlands. Since 1895, plantations were established for poles and for fuelwood. However, field visits show the species being planted in the lowlands along with other eucalypts. It is estimated that more than 100 000 ha has been established in plantations (Hunde et al. 2007), and more are being planted by Governmental Institutions, NGOs and in woodlots by individual farmers. The species sustains the life of most Ethiopians around Addis Ababa and in the highlands.

Cooking fuels are the only significant energy use for most of the Ethiopian urban population. Much energy is consumed by baking the national traditional bread (injera bread made of teff millet of Abyssinia, *Eragrostis tef* (Zucc.) Trotter). The dry leaves of *E. globulus* are the preferred biomass for baking injera. Other uses include poles for traditional house construction and for construction work in the big cities, fence posts, tool handles, transmission poles for telecommunications and electricity, and fibre and particle boards.

Eucalyptus globulus is easy to establish and on good sites seed is obtained 5 years after planting out. The species grow best between 1800 and 2600 m a.s.l. on loamy soils. On a 5-7-year coppice rotation (for poles and firewood) and dense stocking it produces up to 350m^3 ha^{-1}

(Davidson 1995 cited by Eldridge et al. 1994). Some trees can be allowed to grow to a large size and are used as sawn timber but because of growth stresses the output of high-quality boards is low (Eldridge et al. 1994). The species is much recommended as the best performing species in the Central highlands of Ethiopia. On good sites, the species was outstanding with volume production up to 33 m^3 ha^{-1} yr-1 (Pohjonen and Pukkala 1990, Mamo et al. 1995). However, it is noted that it is difficult to predict what would be the yield over a typical range of site types which include shallow, stony soils and degraded land.

Despite the importance of the species to Ethiopia, information on the genetic status of the Ethiopia populations is negligible. As stated by Hunde et al. (2007), the first introductions of *E. globulus* to Ethiopia were successful, the provenance origins and genetic base of the introductions are unknown and probably sub-optimal, and there could be a high degree of inbreeding in the land races that have developed.

A provenance/progeny trial was established in the central highlands, testing progenies from an extensive range of provenances from across the natural range of provenances from across the natural range of *E. globulus* in Tasmania and Victoria. The results revealed Eastern and Western Otway Ranges, Cape Patton and Strzelecki Ranges in Victoria were the fastest growing sub-races, and displayed excellent survival (Hunde et al. 2007). However, a field visit at Ilalaa Gojo site puts in doubt the results following poor management of the field trial and the identification of the original progenies. Furthermore, the field trial has been subject to thinning activities, where superior trees potentially have been harvested. This makes it even more difficult to make any use of the field trial in the future breeding/genetic improvement programs. Therefore, PATSPO perceives the need to provide a plan for future genetic improvement and supply of an on-going seed source of high genetic quality within Ethiopia.

To develop a breeding strategy, it is vital to have information about the biology of the species involved. Aspects including the reproductive mechanisms, potential for asexual propagation, relationships between characters of economic importance and extent of variation and the heritability of such characteristics are all required. At present there is little such information available about the biology of *E. globulus* in Ethiopia. Thus, information from other sources must be used.

E. globulus is generally an outcrossing species, but, in common with most eucalyptus, progeny from open pollination will suffer from a degree of inbreeding due to self-pollination because of the floral biology of *Eucalyptus globulus* (Eldridge *et al*. 1994, Hardner and Potts 1995, Potts *et al.* 2007). Inbreeding depression is severe with selfs being 25% smaller in diameter than controlled cross progenies from the same parents (Hardner and Potts 1995). Patterson *et al. (*2004) reported that outcrossing rates were significantly correlated with the degree of self-incompatibility of individual genotypes, and higher in the upper than in the lower parts of tree canopies. Neither flowering time nor abundance of flowers on individual trees revealed consistent effects outcrossing rates. Controlled pollination is possible and relatively easy due to the large flowers but requires suitable equipment and a certain level of technical expertise. Due

to current situation in Ethiopia, the proposed breeding strategy will not rely on controlled pollination. Moreover, as the most popular germplasm exchange and distribution of the species is by seed, vegetative propagation (grafting, cuttings etc) would not be considered in the proposed breeding strategy.

The strategy would rely on open-pollinated seed for evaluating family performance. The entire breeding population is established in large progeny trials. The progeny trials will be evaluated to estimate genetic parameters of important traits, to test for genotype-environment interactions, to make recommendations on choice of provenances for different sites and to estimate breeding values of individual trees in the progeny trials, before being converted to a seed production area (basically to a seedling seed orchards). All field trials are established in the field using a single tree plot. A series of thinning are expected prior to seed collection and discussed in section 'breeding plan' of this report.

A trip to Ethiopia was made to develop, in close collaboration with the Ethiopia Environment and Forest Research Institute (EEFRI) under the Ministry of Environment, Forest and Climate Change (MEFCC) and PATSPO scientists, detailed breeding plans on *Eucalyptus globulus* and *Afrocarpus falcatus*. During a two-week stay in Ethiopia (December 2018), I discussed with various people *involved* in the genetic tree improvement program and inspected existing E. *globulus* plantings and potential field sites for planned SPAs. Suitable sites were discussed with PATSPO and EEFRI staff members.

4.2 Current situation – genetic improvement of *E. globulus*

The first provenance progeny trial of *E. globulus* was established in 1990 at Ilalla Gojo, Holetta (Central highlands, altitude 2500m a.s.l, rainfall 1200mm and mean temperature 14^{o}C). The main purpose of the trial was to assess variation among provenances and families within provenances of *E. globulus* in terms of growth traits, to develop seed sources for use in afforestation, and to develop breeding populations for future improvement programs.

The provenance/progeny trial covered nine major Australia regions including a total of 299 open pollinated families. A bulk collection of an Ethiopia local land-race from Addis-Ababa, was also included as a single entry in the trial. The results from this study (Hunde *et al*. 2007) revealed Eastern and Western Otways, Cape Patton and Strzelecki Ranges in Victoria were the fastest-growing sub-races, and displayed above average survival. Sub-races from the Tasmanian mainland performed poorly; the Wilsons Promontory sub-race was the slowest-growing and displayed poor survival. The Ethiopian landrace performed well although it was not adequately represented in the trial.

The trial has been well maintained and protected. However, the trial has been developed/managed as timber production plantation and not as a seed production stand (early thinning and wide spacing for seed production, etc.). The felling operations might have led to a negative selection. Moreover, the it was not possible to reconstruct the original field design

showing progeny-identity while visiting the site, making it impossible for a follow-up for any genetic improvement.

A quick assessment in the field show a proportion of stems with spiral grain and double leaders, and some cases of leaf diseases. Although some provenances show outstanding growth that may be captured into the future breeding work, it appears that the environment at the trial site is not very favourable to heavy flowering for the species. Observations at the boarder trees and open-grown trees around the site showed poor to moderate flowering/fruiting for the species. This poor fruiting is due, probably, to high stocking density in the trial and poorly drained soil (Kalinganire 2018, pers. observations) probably both inhibit heavy flowering. Normally, *Eucalyptus globulus* is easy to establish, and on good sites seed is obtained 5 years after planting out (Girma Eshete 2018, pers. communication).

The trial should have been retained as a seedling seed orchard by selective thinning based on superiority in growth traits, absence of spiral grain, double leaders and disease symptoms. However, as discussed, above, the idea could not be achieved following various constraints (poor-to-moderate flowering conditions and tree management not appropriate to seed production). However, if the original design of the trial is obtained, the trial/plantation may be converted into a SPA through the management of coppices of the best progenies. For the planned BSO, and if the original design is available for progeny identification, 20 plus-trees of the best provenances growing at Ilalaa Gojo, Holetta provenance-progeny trial would be selected for the new BSOs based on the best overall breeding values considering health, growth and stem form, but with restrictions on selections within families (Jon Hansen 2019, Pers. communication). Such BSO are to be established on more favourable sites where heavy flowering and seed production is more prolific.

4.3. Proposed breeding plan

Breeding objective

Eucalyptus globulus ssp. *globulus* is grown in Ethiopia for a variety of products including fuelwood, poles and construction timber. Of these, fuelwood and poles are currently considered the most important due to critical shortages of both in Ethiopia.

Tree characteristics required to optimising both poles and fuelwood yield are similar and may be summarised as:

- Survival
- Vigour as expressed by height and diameter growth
- Straight stem and freedom from malformation
- Free of disease or insect attacks
- Reasonably high wood density

Selection criteria

The ideal *Eucalyptus globulus* tree for use in plantations would have the following features:

- Vigour and freedom from disease or pest damage.

- Straight single stem.
- Drought tolerance.
- Good coppicing ability.
- Reasonably high wood density.
- Absence of major defects in the wood, including spiral grain.
- Thin branches that shed easily, and
- Thin bark.

It is essential to determine which of these characteristics may be assessed, and when, and their relative importance in attaining the overall objective as stated above. For this program, PATSPO, the following characteristics are considered essential:

- Adaptation to the environmental conditions in Ethiopia, as determined by survival and health of trees in various field trials (refer to Hunde et al. 2007, Mamo et al. 1995 etc.).
- Vigour, as expressed by height and diameter growth.
- Good stem form – straight stem axis without forks and multi-stem formation.
- Absence of major defects in the wood, including spiral grain, and
- Could be that a flower assessment would be good to be sure that the trees from different provenances (races) are flowering at approximate same time.

Each of these characteristics, except for the last one, may be assessed in field trials at or before half rotation (about 6-8 years for poles). At present little information is available about the relationships between these characters but there is some indication that stem form may be positively correlated with growth traits (e.g. Volker et al. 1989) and that this correlation is reasonably strong. Assessment of wood characteristics is more complex and yet little information is available. It is recommended that initially be restricted to selection against spiral grain which is visible at the stem only.

During the early stages of the breeding program it is suggested that selection be concentrated on adaptation together with growth and stem form. Thus, the objective can be stated in few words – big, healthy, straight trees.

4.4. Genetic resources

Information about the degree of variation within the species is becoming available as the first series of provenance trials planted across many sites in Ethiopia (Hunde *et al*. 2007).

In other countries, present indications are, for growth characters, there are large provenance effects within the species (Appleton *et al.* 1988, Eldridge *et al*. 1994). Volker and Orme (1988) found no single provenance was consistently outstanding over the range of sites. However, the Geeveston Channel, King Island and Otways provenances were among the best in several trials. Also, the King Island provenance was notable for superior stem form. Appleton *et al.* (1988) revealed substantial variation between provenances in stem and branch form. As stated by Volker *et al.* (1990), volume and stem are poorly correlated both genetically and phenotypically. They concluded that substantial improvements can be made in growth whilst

suffering no deterioration in stem form or branch size. The wood density was highly significantly influenced by provenance but not by site (Miranda *et al.* 2001). However, no correlation between growth and wood density was found. For other characteristics, cold and drought tolerance and spiral grain, little information is available, however Volker *et al*. (1994) mentioned frost tolerance being provenance influenced.

Seedlots resulting from single-tree collections from the best provenances of the natural range of the species (see Appendix 4), or from Ethiopian plantations have been proposed as part of the breeding strategy. However, as stated by Volker and Orme (1988) and Eldridge *et al.* (1994) landraces from plantations in several countries grew well, but not better than provenances from natural stands of *E. globulus.* Thus, new introductions for improvement of exotic plantations of the species, since the landraces tested in the current provenance trial were not superior in growth rate to several of the natural provenances (Hunde *et al.* 2007).

The new Breeding Seed Orchards (BSOs) should be established at locations where heavy flowering and seed production of the species is observed. Such sites are identified though field visits and observations on *E. globulus* rowing in the surroundings. The proposed BSOs would include the following progenies if available:

- 80 (about) progenies mainly from Otways and Jerralongs (Victoria, Australia).
- 100 (about) progenies from mainly Flinders Island and Tasmanian Peninsula (Tasmania, Australia).
- 20 plus-trees of the best provenances growing at Ilalaa Gojo, Holetta provenance-progeny trial.
- 5 plus-trees to be collected from Mickey Leland site, Addis Ababa, and
- Seed from 60 plus-trees to be collected from four different locations in Ethiopia as per locations (ref. Roeland Kindt species maps).

The Proposed locations of BSOs include: Bahar Dar and Oromia Forest Enterprises Zones. The critical question is how well do the various local landraces perform relative to new introductions of the best natural provenances. Field trials would help on the various landraces perform relative to new introductions of best natural provenances. It is proposed that the seedlots available for this program should be established in both field trials as Breeding Seed Orchards to:

- Provide the basis for an ongoing seed source of high genetic quality within Ethiopia.
- Provide genetically-improved seed for plantation establishment as soon as possible. Under the option presented below it will be possible to produce reasonable quantities of improved seed for establishing plantations within a period of less than ten years.
- Provide best interim estimates of genetic parameters for the species in Ethiopia. There is little such information available and these trials will provide the best possible quick estimates for developing futures strategy within Ethiopia.
- Allow comparisons of Ethiopian seedlots with Australian seedlots. As there is no information about the origin of the earlier introductions of seed into Ethiopia, it is important to determine how much of the variation within the species is already present in

Ethiopia. In addition, the relative merits of the Ethiopian and Australian seedlots maybe compared on equal basis if all seedlots are planted in the same trials.

- Provide selections for the next generation. As the material in these trials represents single-tree collections of known origin it will form the basis for selection work in establishing an on-going breeding program.
- Provide seed for best possible estimates of genetic parameters. By establishing the trials using single-tree plots the potential for outcrossing will be maximised. After an initial thinning and following the first heavy general flowering in each trial it is proposed to collect seed from the best two or three trees within each family to establish the next series of trials. Such trials would serve as an excellent basis for good genetic parameters and will also form the breeding population for the second generation of the breeding program.
- By establishing the trials (BSOs in this program) on two different sites, both of which are representative of potential plantations areas, it will be possible to get some indication of the presence of any genotype by environment (GxE) interactions. As only two sites are used, only a preliminary indication of the importance of these interactions will be gained. If it appears that such interactions are present, further trials may be required in the future account for such interactions in a breeding program to establish the relative magnitude and importance of such interactions.

4.5. Breeding strategy for *E. globulus* ssp. *globulus*

Definition and background statement

A breeding strategy is a method of selection, combined with a way of mating trees, which may be repeated over several generations.

A breeding strategy should ideally provide for the assessment of variation within a species, acquisition of potentially useful genotypes, generate genetic information about the species, aim to develop the optimum breeding population from which the best possible propagules for commercial use can be produced at any time, maintain pedigree information and maintain genetic variation to ensure continuous and long-term improvement of the species (Barnes, 1987). With these aims in mind, an assessment must be made of the current and proposed services for the species, facilities and staff available to the program and a feasible strategy determined.

Given the current levels of expertise available within Ethiopia and the financial restrictions/limitations, a simple but complete breeding strategy is proposed. It relies on open pollination and seedling seed orchards. The strategy relies on the use of reasonably large field trials to be established using single tree plots. At approximately one third rotation age (about 5 years) all trees are assessed for desired characteristics and all selection decisions are based on these data. The first thinning is then undertaken and following the first subsequent general flowering in the trials, seed is collected for the next generation's breeding population.

By planting such trials at sites which represent the range of potential plantations sites it will be possible to obtain reasonably robust estimates of genetic parameters and family mean performance, to get an indication of whether genotype x environment interactions are likely to

be important and to provide genetically-improved seed to the major growing areas for the species within the shortest possible period. By using trial sites within the most important growing regions the selection work will be undertaken in the same environmental and silvicultural conditions under which the orchard seed will be established. Thus, the selection for adaptation is incorporated into the program.

There is a requirement for maintenance of complex and accurate records so that future work may be planned, and the progress of the breeding program monitored. Information to be collected will include the following:

- Establishment reports for the trials.
- Climatic information.
- Maps of trial layouts.
- Pedigree information, and Data from assessment of trials.

It is essential that such information be recorded in a logical and systematic manner. It is suggested that a system be developed in the very early stages of the program so that all information will be accessible and easily interpreted as the program progresses.

Outline of the strategy – An outline of this basic strategy is given in Figure 1. The strategy is based on planting the entire breeding population in large progeny trials using single-tree plots wit family identity retained. These trials are converted into seedling seed orchards by a two-stage thinning process. The first thinning is done at about one third rotation age (approximately at 5 years) and is mainly a within-family thinning with the worst trees in each family being removed. Only the very worst families are removed completely.

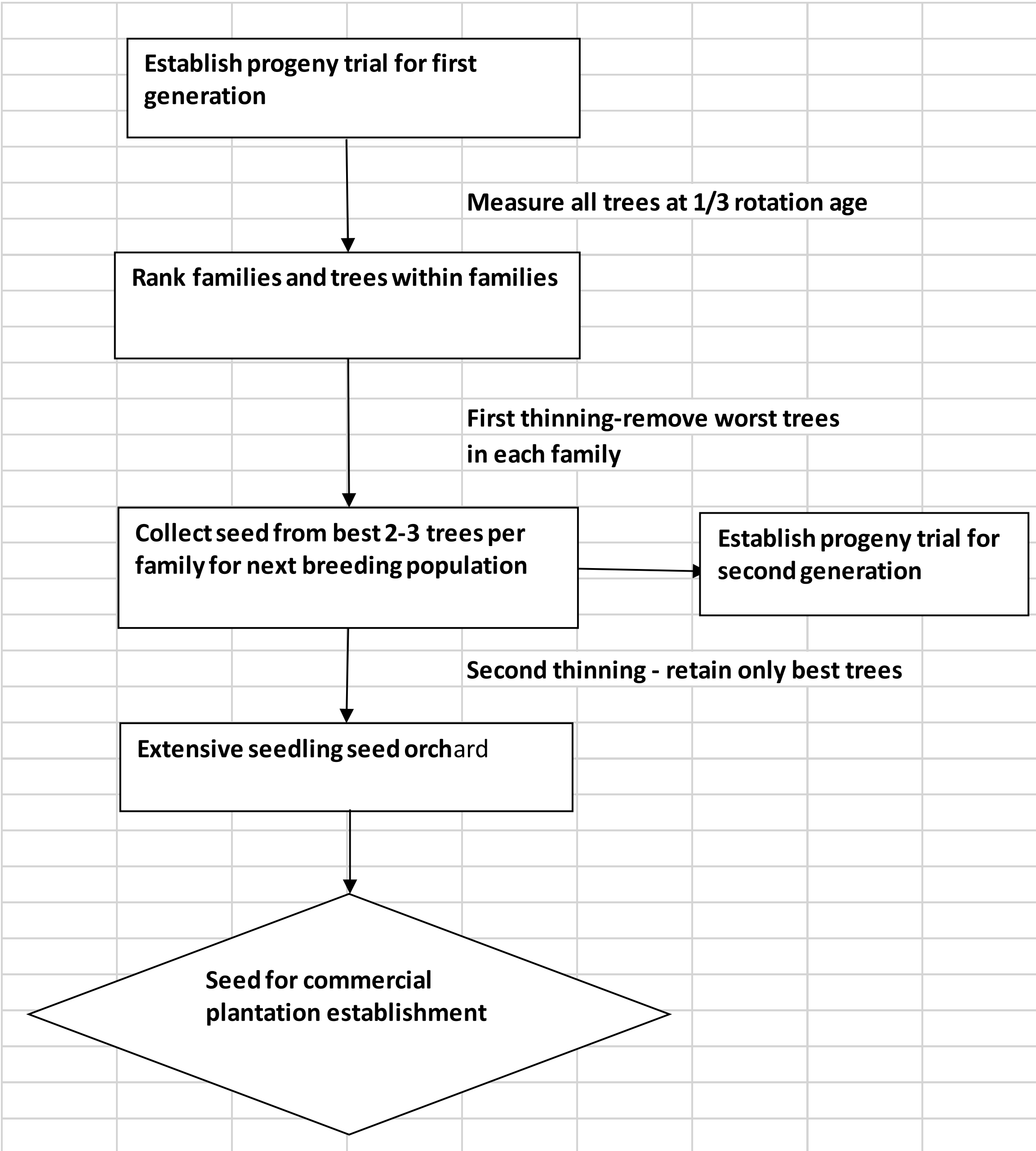
Following the first flowering after thinning, seed is collected from the best two or three trees within each family (with individual identity of the tree retained0 to provide the basis of the breeding population for the next generation. A second thinning is then done to convert the progeny trial to a seedling seed orchard. The very best trees are retained to produce high quality seed for immediate plantation establishment. However, some other trees would be retained to keep genetic diversity in the stand.

By using the one trial for a variety of purposes, this strategy optimises use of limited resources whilst remaining flexible. The initial trials are combined provenance/progeny trials which will also serve as the current breeding population, and will provide seed for the next generation's breeding population before being converted to seedling seed orchards to produce seed for plantation establishment. Each time a progeny trial is established it is possible to incorporate new seedlots into the breeding population for testing and evaluation, while the two-stage thinning process ensures that the seed produced from seed orchard is of the highest possible quality.

The use of a two-stage thinning process allows a broad genetic base to be maintained in the breeding program. Very few families are removed in the first round of thinning prior to collection of seed to establish the next breeding population. Subsequently, the very best are

retained after the second thinning to ensure the genetic quality of the seed orchards trees from which large amounts of seed are required to establish plantations. The narrowed genetic base resulting from the second thinning is not used for further breeding purposes.

Figure 1. Schematic diagram representing the basic strategy for *Eucalyptus globulus*



Proposed design for field trials

It is proposed that the progeny trials be established using either an incomplete block design or a randomised complete block design with single-tree plots. These reduce the risk for large environmental variations within a replication/blocks. Use of single tree plots allow:

- Most efficient use of seed and providing good estimates of each individual's performance under competition with different genotypes.
- Chance of retaining all best trees is maximised. Thinning can be restricted to removal of the worst trees and the need to remove good trees from a multiple-tree plot is avoided.
- Pollen distribution across the trial will be as diverse and uniform as possible.
- Outbreeding will be maximised as each tree will be surrounded by different genotypes.

Regarding sites, the following factors should guide sites selection:

- Sites should be representative of the environment in which future plantations will be established. All selection work to be based on tree performance under the environmental and silvicultural conditions that are prevailing in Ethiopia.
- Sites should be sufficiently uniform to allow valid comparison of genotypes.
- Trials are planted where flowering will be abundant and where seed set will be maximised.
- Trials should be on good quality sites and receive good maintenance at this seed is extremely valuable and is the basis for an ongoing breeding program,
- Trials should be isolated from other stands of compatible eucalypts to prevent potential pollen contamination from unselected trees.
- Trials to be protected from damage and illegal harvesting.

Description of operations implementing the breeding strategy

Year 1: Establish large progeny trials.

Year 2 and 3: Maintain the field trials as per routine practices.

Year 4: Measure all trees for stem diameter at breast height and assess trees for health, presence of spiral grain and stem form. Analyse the data to provide the rankings of families and of trees within family for each trait. The variance, heritability and correlations for the traits assessed should be estimated.

Year 5: Determine which trees to be removed and carry out the first thinning.

Year 6. During flowering the trial should be regularly observed to determine the flowering period for each family. As it is intended to use the seed resulting from this flowering as the basis for the next generation's breeding population, it is important that outcrossing is maximised. Families which flower either earlier or later than the maximum flowering period should be noted as the amount of outcrossing may be reduced for these families.

Year 7: Collect seed from the best two or three trees within each family and maintain the individual tree identity for each seedlot. Carry out the second 'heavy' thinning to convert the trial to a seedling seed orchard.

Year 8. Establish the next trial, second generation's breeding population, using seed collected from trees in the first trial plus appropriate additional seedlots available. Collect first seed crop from the seedling seed orchard.

4.6. Recommendations for future work

The strategy detailed for the first generation is equally applicable to later generations, with the time scale for operations being the same. The strategy is flexible and allow for the introduction of new seedlots at each generation.

Key points to take into consideration at all stages include:

- New seedlots may be introduced into the program at each generation as more information becomes available. The nature of these seedlots will depend upon the results of the first progeny trials which are also provenance trials. These trials will provide information as to the most promising areas for further seed collections.
- The number of seedlots retained from each introduction will change in a systematic manner. Seed from native stands may contain some percentage of inbreeding due to neighbourhood effects (Eldridge *et al.* 1994, Zheng *et al.* 1997). Therefore, when seedlots are introduced from native occurrences, the performance of the families will be influenced by neighbourhood inbreeding in their original stands (Eldridge *et al.* 1994). The performance of a family in the first generation will not be a true indication of the genetic merit of this family until the next generation.
- The number of parents involved in the breeding program will increase over the first few generations as new seedlots are introduced.
- As more information becomes available regarding the relative importance of variation between and within provenances, decisions can be made regarding future seed collections and where selection emphasis should be placed.

For each generation, well designed progeny trials using single tree-plots will form the breeding population which will be managed as discussed in this strategy. The aim is to minimise the generation interval and to produce reasonable amounts of genetically-improved seed at each generation.

Ideally, when it is intended to collect seed from a specified stand of trees (e.g. Seed production areas, Seedling seed orchards), it is essential that the stand be isolated, as far as possible, from potential sources of pollen contamination. This requirement may be difficult, as the species is growing mostly everywhere in Ethiopia. However, such isolation is necessary to avoid the possibility of reducing the genetic quality of the resulting seed due to pollen coming from non-selected trees and to avoid the possibility of producing inter-specific hybrids.

It is essential that trials are not planted adjacent to any other eucalypts which may cross-pollinate with the planned seed production areas. It is advisable that such areas are surrounded by a band of at least 100m wide of another species that will not hybridise with E. globulus. This band will serve as a dilution zone for foreign pollen. Possible species to use for the purpose

would be a non-eucalypt species (e.g. pines, cypress, *Afrocarpus* species) or a eucalypts species from different subgenera.

4.7. **References**

Appleton, R., Cameron, J.N., Dean, C.A, and Whiteman, P.J. 1988. Combined and multiple trait selection in a 16.5-year-old *Eucalyptus globulus provenance trial* (VRD13). *Gippsland Technical Report* 88-17. APM Forests, Morwell, Victoria, Australia.

Barnes, R.D. 1987. The tree breeding programme in Zimbabwe. Oxford Forestry Institute, University of Oxford, England.

Davidson, J. 1995. Eucalyptus tree improvement and breeding. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa, Ethiopia.

Eldridge, K., Davidson., Harwood, C., and van Wyk, G. 1994. Eucalypt Domestication and Breeding. Clarendon Press, Oxford.

Hardner, C.M. and Potts, B.M. 1995. Inbreeding depression and changes in variation after selfing *Eucalyptus globulus* subsp. *globulus*. *Silvae Genetica* 44, 46-54.

Hunde, T. Gizachew, B. and Chris Harwood. 2007. Genetic variation *in Eucalyptus globulus* in Ethiopia. *Australian Forestry*, 70 (1): 48–52.

Mamo, N., Habte, B. and Beyan, D. 1995. Growth and form factor of some indigenous and exotic tree species in Ethiopia. Forestry Research centre, Ministry of Natural Resources Development and Environmental Protection, Addis Ababa, Ethiopia.

Miranda, I., Helena-Almeida, M. and Pereira, H. 2001. Provenance and site variation of wood density in *E. Globulus* Labill. at harvest age and its relation to a non-destructive early assessment. *Forest Ecology and Management* 149 (1-3): 235-240.

Patterson, B, Vaillancourt, R.E, Pilbeam, D.J. and Potts, B.M 2004. Factors affecting variation in outcrossing rate in *Eucalyptus globulus. Australian Journal of Botany* 52(6): 773-780.

Pohjonen, V. and Pukkala, T. 1990. *Eucalyptus globulus* in Ethiopian forestry. *Forest Ecology and Management* 36: 19-31.

Potts, B.M., McGowen, M.H., Williams, D.R., Suitor, S., Jones, T.H., Gore, P.L. and Vaillancout, R.E. 2007. Advances in reproductive biology and seed production systems of Eucalyptus: The case of *Eucalyptus globulus*. *South. For.* 70:145-154.

Volker, P.W. and Orme, .K. 1988. Provenance trials of *Eucalyptus globulus* and related species in Tasmania. *Australian Forestry* 51:257-265.

Volker, P.W., Tibbits, W.N., Dean, C.A and Ravenwood, I.C 1990. Genetic parameters and gains expected from selection in *Eucalyptus globulus* Labill. in Tasmania. *Silvae genetica* 39: 1-18.

Volker, P.W., Owen, J.V., and Borralho, N.M.G. 1994. Genetic variances and covariances for frost tolerance in *Eucalyptus globulus* and *E. nitens*. *Silvae Genetica* 43:366-372.

5. Breeding plan of *Afrocarpus falcatus*

5.1 General introduction and biology of the species

The species in Ethiopia - *Afrocarpus falcatus* (Thunb.) C.N. Page, Podocarpaceae family (syn. *Afrocarpus gracilior, Decussocarpus falcatus, D. gracilior, Nageia falcatus, Podocarpus falcatus, P. gracilior*) grows 45m high and 250cm in diameter in 11 out of the 14 floral regions recognized in Ethiopia (Teketay 2011).

The species grows at 1500-3000 m altitude in areas with 1200-1800 mm rain per year (Mihretu 2004, Teketay 2011). It prefers a warm and humid climate, in dry areas plantations fail. Tolerates moderate frost but not drought. Natural stands of Yobenercy Forest, Munessa and Changtu Forest, Dodola Zone both in Oromia region, confirmed existing and outstanding individuals (Kalinganire 2018: Pers. observations). Moreover, plantations on-farms and in SPA of Yergalem, Hawassa, and a stand at Arjo have exceptional specimens worth selecting and including into the proposed BSOs. *Afrocarpus falcatus* is a canopy tree of the mixed evergreen forests. In the Afromontane forest it is frequently one of the dominant or co-dominant species ('Podocarpus forest' or e.g. Juniperus-Podocarpus forest). It is often seen persisting in patches of relic forest and as a single tree left in derived grassland or farmland.

It is widespread in a broadleaved Afromontane rain forests, in the Highlands of Ethiopia as a dominant or co-dominant tree species (Mihretu 2004). *Afrocarpus falcatus* has become threatened, because of selective logging for many decades, whereas the reproductive potential has rapidly declined (Mihretu 2004). The species is very vulnerable to logging, a practice which likely claimed many large, ancient specimens.

The species is a multipurpose species, growing relatively fast and to large size, on both on-farms and in forests, with a wide range of socio-economic and environmental importance. Suitably manufactured and conditioned, it produces wood suitable for many purposes (Aerts 2008, Teketay 2011). It is also useful for fuelwood, charcoal, medicine, poles, paper pulp, shade, and ornamental purposes. Despite its great importance, the species is on the verge of local extermination because of its unsustainable exploitation over the last several decades (Teketay 2011).

The biology of the species - Natural occurrences are at 1500-3000 m altitude. The species occurs in mountain forest from Ethiopia through Kenya, Tanzania, Rwanda, Congo (RDC) and Mozambique to eastern and southern South Africa, including Swaziland and Lesotho (White 1983, Aerts 2008, Teketay 2011, Joker 2013). *Afrocarpus falcatus* prefers places within an annual rainfall of (80-) 1200-1800) (-2200) mm and mean temperatures of 13-20^{o}C (Aerts 2008; Kabera 1992, Teketay 2011).

The species is dioecious, the male and female reproductive systems occurring on separate plants (Geldenhuys 1993, Aerts 2008, Kalinganire 2019: Personal observations). The male to female ratio in a stand is not known. The pollen is dispersed by wind, but most of it does not

get far from the male tree. Fruiting starts as early as 10 years after planting. Seed production varies from year to year. Female trees produce seeds irregularly mostly with an interval of 2-4 years. Seeds take about a year to mature. The seed is adapted to dispersal by bats, birds and mammals - Colobus monkeys, rodents, bush pigs, turacos and hornbills. Propagation of the species is by seed. Seed collected from the ground are often infected with fungus, which reduces the germination rate. Therefore, scarification of fresh seed, preferably within 12 months after collection, by removing the seed coat (exocarp) is recommended for a quick and uniform germination. Seed germinates best at 25°C (20-30°C; Kabera 1992). At the time of transplanting, care should be taken not to damage the taproot.

Afrocarpus falcatus is susceptible to drought, tolerates light frost but young seedlings are susceptible. The species has been recommended for plantations with a high demand in different countries including Ethiopia, Rwanda, South Africa and Tanzania (Kabera 1992, Derero 2011). It performs better on well-drained, deep, humus-rich and light-textured soils with pH of 5-7 (Mihretu 2004, Kabera 1992). The optimum spacing is 3 m x 3 m in plantations. Survival rates over 95% have been reported in high rainfall and low temperature areas, e.g. Belete, Ethiopia (Orlander 1986) and Rutovu, Rwanda (Kabera 1992). Annual growth can be over 1m in height and 1cm in diameter at breast height, at least until 15 to 20 years old plantings (Kabera 1992). The tree is very sensitive to competition, and thinning is necessary for good diameter growth. Trees planted in agroforestry systems show better growth in both South Africa and Rwanda (Kabera 1987), and in Ethiopia (Personal observations, 2018).

5.2 Current situation –conservation and genetic improvement

Afrocarpus falcatus is widely scattered at low density and has a low recruitment rate (Geldenhuys 1992). Many natural forests where the species occurs continue to be lost through deforestation, a process which will deplete the genetic resources and limit the potential for sustainable production of *A. falcatus*. Therefore, apart from increasing efforts at genetic improvement of *Afrocarpus falcatus*, attention should be given to genetic conservation. *In-situ* conservation in natural areas, is one of the options, but may be complicated by many factors such as national policy and social issues (e.g. land use in natural forests) in Ethiopia. *Ex-situ* conservation through planted stands of selected genotypes is simpler and more practical. Moreover, *circa-situm* conservation on-farms in agroforestry systems especially around the natural occurrences of the species.

The different populations need to be adequately conserved if the full breadth of genetic variation across the species is to be maintained. Increased knowledge of the species' biology and of the spatial distribution of its genetic diversity will help ensure future availability of highly productive seed sources for reforestation. In Ethiopia *A. falcatus* has become threatened because of selective logging for many decades, whereas the reproductive potential has rapidly declined. In other countries populations also have diminished seriously, e.g. in Tanzania, whereas many of the larger *A. falcatus* trees have disappeared from South Africa as well. *Afrocarpus falcatus* is included in the IUCN Red List as vulnerable.

Genetic variation present within wild populations of forest species should be characterized during the domestication process. The variation can be assessed by selecting and testing seedlots, collected from geographically distinct populations within the natural and sometimes naturalized distribution, in provenance and progeny tests. Species with a wide distribution like *A. falcatus* are expected to show considerable geographic variation in growth traits and possible resistance to pests and diseases.

Characterization of such variation will reveal outstanding provenances and individual within provenances. Thus, provenance testing should be given high priority at the outset of the program. An important aspect of provenance selection programs is the need to include material from a wide range of origins. The range-wide *A. falcatus* seed collections, to be included into Ethiopian BSOs, are planned and details given in section 5.3.

Information on provenance trials of the species are scanty. In East Africa, Negash (2003) reported significant differences in germination and early growth of seed provenances from Central, Southern and Eastern Africa. Some e*x-situ* conservation and provenance trials have been carried out in Ethiopia and South Africa. In Ethiopia, *Podocarpus gracilior* provenance trials were established in South Western research stations. Tadesse (2017) stated that the species showed remarkable growth performance at Aman and Belete Chaka. However, provenances sources and related publications are not available.

In the South African experiments, it was demonstrated that seeds from provenances near the afforestation site showed better results after germination than those from provenances from further away. Provenance trials were initiated to evaluate various South African sources/provenances. Significant variation in growth was obtained 11 years after planting (Geldenhuys and von dem Bussche 1996). Studies on water use of the species, genetic variation of the species and variation in timber properties of the provenances were recommended. Therefore, the proposed BSOs would aim producing improved plant materials, but also help assessing genetic variation within the species.

5.3 Genetic resources

Seedlots resulting from single-tree collections from the natural range of the species, and from the Ethiopian plantations have been proposed as part of the breeding strategy.

Thus, the new Breeding Seed Orchards (BSOs) should be established at locations where heavy flowering and seed production of the species is observed. Such sites, and as earlier discussed, would be at about 1500-3000 m altitude, an annual rainfall of 1200-1800 mm and a mean annual temperature below 20^{o}C. The site should be frost free. The recommended spacing is 3 m x 3 m.

The two proposed locations of *A. falcatus* BSOs are in the Ethiopian Highlands (see above criteria) and are including Munesa, Shambo (Western Ethiopia) and Addis-Ababa Zones.

New proposed BSOs will include the following progenies:

- 60 plus-trees collections from four locations to be proposed by Roeland Kindt as per the species distribution maps of the species in Ethiopia. These would exclude areas provided hereunder in the report.
- 20 plus-trees from Yobercy Forest, Munesa.
- 20 plus-trees from Chongitu Forest, Dodola Zone.
- 20 plus-trees from Addis Abeba-Alem near Holetta.
- 10 plus-trees from Yergalem SPA.
- 30 plus-tree from on-farms ‘plantings’ from environs of Yobercy, Chongtu and Addis-Ababa natural stands.
- 40 individual trees from natural stands (10 each from Kenya, Malawi, Tanzania and Rwanda).

It is proposed that the seedlots available for this program, after seed collection, should be established in both field trials as Breeding Seed Orchards to:

- Provide the basis for a reliable and sustainable seed source of high genetic quality within Ethiopia.
- Provide genetically-improved seed for plantation establishment as soon as possible. Improved seed for establishing plantations within a period of less than 15 years. Seed production starts as early as 8-10 years.
- Provide best interim estimates of genetic parameters for the species in Ethiopia. There is no such information available and these trials will provide the best possible quick estimates for developing futures strategy within Ethiopia and other countries growing the species as a fast-growing indigenous tree species.
- Allow comparisons of Ethiopian seedlots with East and southern African seedlots.
- Provide selections for the next generation. As the material in these trials represents single-tree collections of known origin it will form the basis for selection work in establishing a breeding program.
- The potential of outcrossing would be maximised as the trials are using single-tree plots. After an initial thinning and following the first heavy general flowering in each trial it is proposed to collect seed from the best two or three trees within each family to establish the next series of trials. Such trials would serve as an excellent basis for good genetic parameters and will also form the breeding population for the second generation of the breeding program.
- By establishing the trials (BSOs in this program) on two different sites, both of which are representative of potential plantations areas, it will be possible to get some indication of the presence of any genotype by environment (GxE) interactions.

5.4 Breeding strategy for *Afrocarpus falcatus*

Background statement and Assumptions: The species is dioecious (Geldenhuys 1993, Aerts 2008), medium-sized tree to large tree up to 6m tall. However, information of other features of its reproductive systems is limited. Given the limited knowledge of the floral biology of the

species, the proposed strategy relies on open-pollinated management of breeding populations for the establishment of seedling seed orchards for operational seed production.

Open-pollinated breeding strategies have many advantages, being simple to implement, quick in turn-over, and low-cost in their operation, but still capable of providing substantial gains. The breeding population, established as large open-pollinated progeny trials, is of a broad genetic base, and provides for selection of outstanding individuals which are used, at later stages, for establishment of clonal seed orchards.

Our assumptions are that operational plantations including on-farm plantings will use seedlings. It is further assumed that there is good correlation for growth performance between outstanding trees in open-pollinated progeny trials and offspring in trials. In other words, selection of the outstanding trees in the progeny trials (trees grown from seed) will accurately select individuals, both male and female individual trees, which will also have superior performance.

The proposed strategy has a long-term thrust which will continuously maintain a breeding plantation of a well-adapted and broad genetic base. The breeding program will import new seed from a wide range of provenances to create the broadly-based breeding populations. As selection of candidate plus-trees of the species is on-going, it is proposed to include seed collected from these plus-trees in the program to allow comparison with material to be collected from the natural occurrences.

Breeding objective: *Afrocarpus falcatus* is grown for a range of products of which timber, often traded as 'podo' or 'yellow wood' is, in general, highly valued for ship building, but also used for poles, panelling, furniture, boxes and plywood. It is suitable for construction, flooring, joinery and mine props (Aerts 2008). In Ethiopia, it is mainly grown for timber, and the proposed breeding plan would target timber as the main product. Fuelwood is also important, but it is regarded as a by-product from thinning and pruning. Therefore, the ultimate objective of this breeding program is to maximize the yield and quality wood/timber in plantations.

Selection criteria: Ideally the trees of *Afrocarpus falcatus* suitable for production of timber should possess some characteristics. Tree characteristics required to optimising yield are similar and may be summarised as:

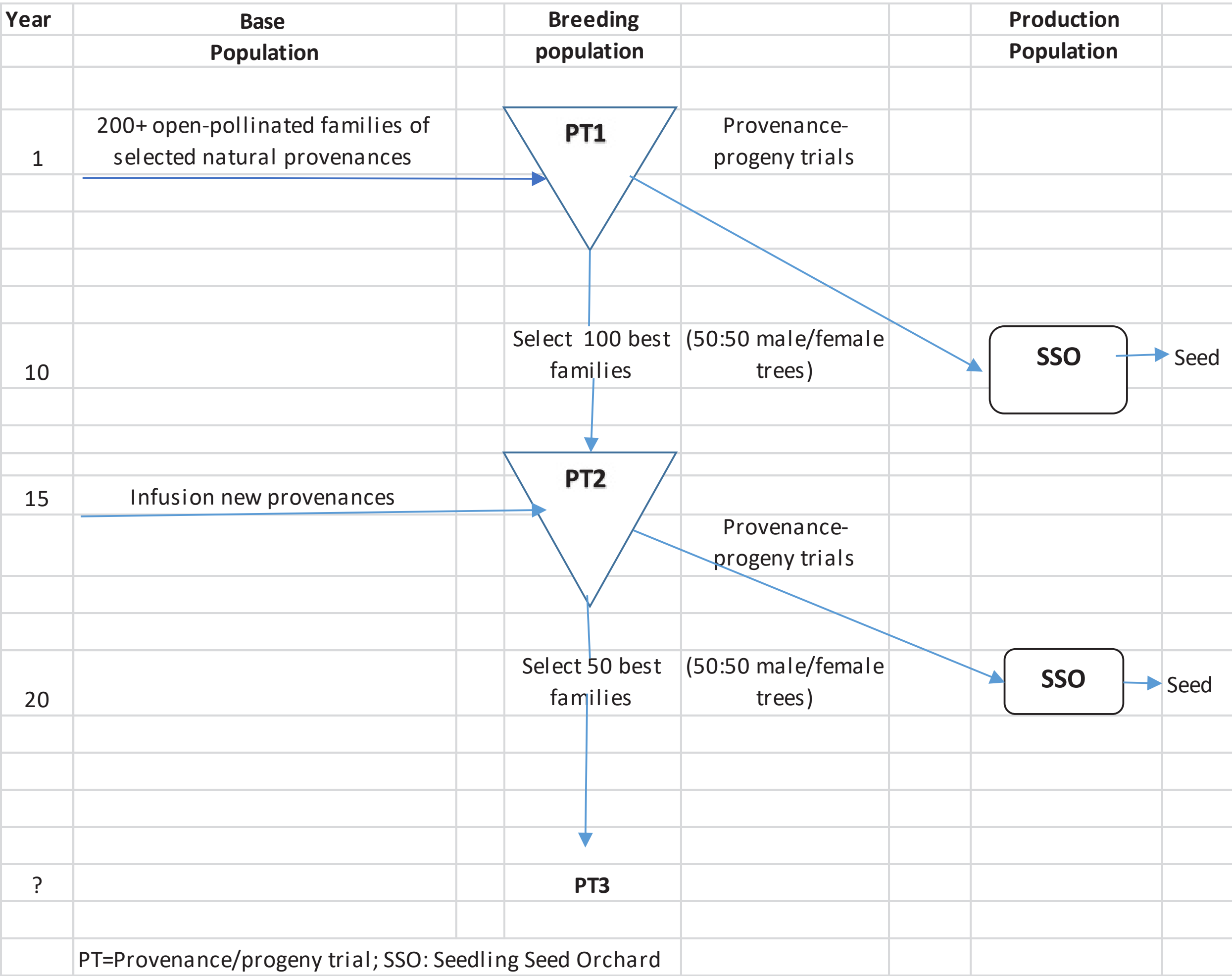
- Tree vigour (growth).
- Straight single stem and freedom from malformation.
- Free of disease or insect attacks.
- Reasonably high wood density, and
- Thin branches that shed easily.

Proposed improvement strategy for *Afrocarpus falcatus*

Improvement strategy – the main product of *Afrocarpus falcatus* in Ethiopia is its high-quality timber and therefore the improvement objective is to maximize the production of timber from planted stands. Selection criteria in the first generation of improvement are increased wood volume production, and improved stem form. Improvement in wood properties affecting the quality of timber could be considered in second and subsequent generations of breeding.

An improvement strategy considering the non-existing of provenance trials to serve as founding populations for selection of the species is suggested in Figure 2. A detailed breeding plan describing the operations step by step, and their timing, would have to be prepared considering the available Ethiopian staff, available financial resources and the range of target environments for which breeding is being conducted.

Figure 2. Schematic diagram representing the basic strategy for *Afrocarpus falcatus*



Proposed design for field trials and detailed description of operations

It is proposed that the progeny trials be established using either an incomplete block design or a randomised complete block design with single-tree plots. These reduce the risk of large environmental variations within a replication. Use of single tree plots allow:

- Most efficient use of seed and providing good estimates of each progeny's performance under competition with different genotypes.
- Chance of retaining all best trees (both males and females) is maximised. Thinning can be restricted to removal of the (really)worst trees and the need to remove good trees from a multiple-tree plot is avoided.
- Pollen distribution across the trial will be as diverse and uniform as possible.
- Outbreeding will be maximised as each tree will be surrounded by different genotypes.

Regarding sites, the following factors should guide sites selection:

- Sites should be representative of the environment in which future plantations will be established. All selection work to be based on tree performance under the environmental and silvicultural conditions that are prevailing in Ethiopia.
- Sites should be sufficiently uniform to allow valid comparison of genotypes.
- Trials are planted where flowering will be abundant and where seed set will be maximised.
- Trials should be on good quality sites and receive good maintenance at this seed is extremely valuable and is the basis for an ongoing breeding program,
- Trials should be isolated from other stands of compatible *Afrocarpus* to prevent potential pollen contamination from unselected trees.
- Trials to be protected from any physical damage and illegal harvesting.

Description of operations implementing the breeding strategy

Year 1: Establish large progeny trials of 200 open-pollinated families. Two hundred seedlots (see details under section 5.3) resulting from individual-tree collections from the species' natural and delivered occurrences have been collected by the PATSPO program. The mother trees were selected as good healthy, straight and big dominant trees. These seedlots will form the basis of the first generation's breeding population. The proposed strategy is based on open-pollinated-mating in a breeding population.

Year 2 and 3: Maintain the field trials as per routine practices.

Year 10: Measure all trees for stem diameter at breast height and assess trees for health, stem form and flowering (sex ratio). Analyse the data to provide the rankings of families and of trees (males and females) for each trait. The variance, heritability and correlations for the traits assessed should be estimated. During flowering the trial should be regularly observed to determine the flowering period for each family, including sex ratio. As it is intended to use the seed resulting from this flowering as the basis for the next generation's breeding population, it is important that outcrossing is maximised. Families which flower either earlier or later than the maximum flowering period should be noted as the amount of outcrossing may be reduced for these families.

Year 10-12: Determine which trees to be removed and carry out the first thinning. In this thinning, emphasis is given to selection for adaptability and vigour. Therefore, more than half of

the families (60%) the biggest, straightest and healthiest trees in best families will be retained. The rate of males and females to be retained per family would be 50:50. In any case, diversity within each family needs to be retained.

Year 15: Collect seed from the retained trees and maintain the individual tree identity for each seedlot. Carry out the second thinning, if needed, to convert the trial to a final seedling seed orchard.

Year 15-20. Establish the next trial, second generation's breeding population, using seed collected from trees in the first trial plus appropriate additional seedlots available. Collect first seed crop from the seedling seed orchard. Maintain the identity for each individual tree from which seed is collected. Keeping many the families from a range of provenances ensures wide outcrossing between provenances which is likely to result in intra-specific hybrid vigour and generate increased availability for selection in subsequent generations.

The breeding population is comprised of 200 open-pollinated families. The population is established as large-open-pollinated progeny trials, of a broad genetic base and provides for selection of outstanding individuals which are used the establishment of clonal seed orchards. The breeding cycle in each generation is 10 years (just time of the first flowering period).

The strategy begins with planting the entire breeding population in large open-pollinated progeny trials using single tree plots and family identity retained.

The progeny trials are subject to two thinning. After ranking the families and trees within family at 1/3 rotation (10-12 years), the first thinning, which is mainly a within family thinning, is carried out, keeping 50% best (biggest, straightest and healthy) trees of the best family. By keeping trees of best families, it increases the chance of having both male and female trees per best family for selection. Consideration is, however, given to ensure that there is approximately a 50:50 ratio of males and females remaining in the breeding population which will supply open-pollinated seed for the second generation's breeding population.

To maintain the broad genetic base of the breeding population each generation, trees from more than about 60% of families are selected. The breeding population should have at least a sex-ratio of 50:50, and more than 60% is large enough to provide genetic gains for several generations. A breeding population of this size is considered large enough to sustain an entire breeding program for many generations of breeding and testing even without further infusion of new material (White 1992). Infusion of new genetic material from external populations (e.g. native stands, local land races etc) each generation into the breeding population to maintain the 200-population size will further ensure a broadly-based breeding population for recurrent selection for general combining ability.

These infusions will also give the opportunity to introduce potentially superior new material, not yet identified. This is because the families will be unrelated, and all the trees are expected to be highly heterozygous as the species is dioecious (i.e. dioecy is an outcrossing mechanism).

5.6 Recommendations for future work

The individual family collections from range-range wide provenance collections will be used to set-up breeding populations. Approximately 200 families from superior provenances, natural occurrences and if feasible families from other countries may be imported and included in the provenance-progeny trials, would be planted in provenance-progeny trials. Sites would be converted to seedling seed orchard by heavy selective thinning. It would deliver somewhat improved seed within 10-15 years.

The strategy described for the first generation, which relies on open-pollinated mating, is applicable to later generations with the same time-scale for operations. The strategy calls for the introduction of new genetic material at each generation to combine the overall selections. Introducing new genetic material each generation and making large selections from the previous generation ensures the continuity of a broadly-based breeding population for recurrent selection for general combining ability.

In future generations, with adequate knowledge of the floral biology and resources permitting, it may be possible to embark on control-pollinated mating of the best individuals in the breeding population to produce the outstanding families for mass vegetative multiplication for industrial plantations. Thus, the choice of male and female progenies would be based on general combining ability from the large progeny trials. Careful consideration must be given regarding the benefit and cost before embarking on control-pollinated breeding option as gain from open-pollinated breeding population has been found to be only slightly inferior to that from full-sib breeding populations for some species (e.g. Shelbourne 1992).

4. Consulted documents

Aerts, R. 2008. *Afrocarpus falcatus* (Thunb.) C.N.Page. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, The Netherlands.

Derero, A. 2011. Toward a tree seed system that guarantees quality and satisfies demand in Ethiopia. *In*: Derero, A., Fantu, W. and Eshetu, Z. (editors). Trends in Tree Seed Systems in Ethiopia. Proceedings of Workshop on Tree Seed Systems in Ethiopia from 21-22 June 2010. Forestry Research Center, Ethiopia Institute of Agricultural Research. Addis-Ababa. PP.43-56.

Geldenhuys, C.J. 1993. Reproductive biology and population structures of *Podocarpus falcatus* and *P. latifolius* in Southern Cape forests. *Botanical Journal of the Linnean Society,* 112 (1): 59-74.

Geldenhuys, C.J. and von dem Bussche, G.B. 1996. Performance of *Podocarpus falcatus* provenances in South Africa. *Southern African Forestry Journal,* 178:15-24.

Kabera, I. 1987. Comportement des essences autochtones introduites a Rutovu (32 ans) après la mise en place. Note Technique no. 1. Institut des Sciences Agronomiques du Rwanda (ISAR), Butare, Rwanda. 20pp.

Kabera, I. 1992. Le *Podocarpus falcatus* : espèce indigène prometteuse pour les plantations au Rwanda. Institut des Sciences Agronomiques du Rwanda. Note Technique no. 7. Institut des Sciences Agronomiques du Rwanda (ISAR), Butare, Rwanda. 45pp.

Mihretu, M. 2004. Growth performance of some indigenous and exotic tree species in South Western Ethiopia. Research Report no. 58. Ethiopian Agricultural Research Organization, Addis Ababa.

Negash, L. 2003. *In-situ* fertility decline and provenance differences in the East Africa yellow wood (*Podocarpus falcatus*) measured through *in-vitro* seed germination. *Forest Ecology and Management*, 174:127-138.

Orlander, G. 1986. Growth of some forest trees in Ethiopia and suggestions for species selections in different climatic zones. Forestry Research Note, 2. Forestry Research Center: Addis Ababa.

Shelbourne, C.J.A. 1992. genetic gains from different kinds of breeding population and seed or plant production population. *South African Forestry Journal* 160:49-62.

Teketay, D. 2011. Natural regeneration and management of *Podocarpus falcatus* (Thunb.) Mirb. In the Afromontane Forests of Ethiopia. In: Gunter, S., Weber, M., Mosansl, R. (eds) Silvicutlure in the Tropics. Tropical Forestry, vol. 8. Springer, Berlin, Heidelberg.

Tadesse, W. 2017. Status of tree improvement and gene conservation in Ethiopia. Consultant Report to PASPO/ICRAF. Addis-Ababa.

White, F. 1983. The vegetation of Africa. UNESCO Natural Resources Research, 20:1-356. Rome, Italy.

White, T.L. 1992. Advanced-generation breeding populations: size and structure. In Proceedings of the IUFRO Conference. Breeding Tropical Trees, october 12-16, 1992, Cali, Colombia.

6. APPENDICES

Appendix 1: Terms of reference for the Consultancy

Consultancy on assessment, description and use of linkages between previous and ongoing tree improvement in Ethiopia and the PATSPO BSO establishment programme November 2018 and March/April 2019

BACKGROUND

Provision of Adequate Tree Seed Portfolios (PATSPO) to enhance productivity and resilience of Forest Landscape Restoration in Ethiopia is a project supported by a grant from the Government of Norway through the Norwegian International Climate and Forest Initiative (NICFI). The project is implemented by the World Agroforestry Centre (the International Centre for Research in Agroforestry - ICRAF) in close collaboration with the Ethiopia Environment and Forest Research Institute (EEFRI) under the Ministry of Environment, Forest and Climate Change (MEFCC), and other institutions working in the tree seed sector in Ethiopia. PATSPO is a four-year project 2017 – 2020 based on an agreement between the Royal Norwegian Embassy in Ethiopia (RNE) and ICRAF.

PATSPO is designed to support Ethiopia in its ambitious programmes of forest landscape restoration with a commitment to restore more than 20 million ha of degraded forest landscapes within the next 20 years.

A major challenge of forest landscape restoration work is that it generally requires the use of planting material in large quantities of a broad spectrum of genetically diverse, healthy and productive tree species.

PATSPO addresses this major challenge by providing a multiple tree species programme able to provide:

1. organizational setup of the tree seed sector, including stakeholder identification and roles and responsibilities, based on a sector analysis;
2. species specific knowledge for most priority tree species;
3. a built up of the tree genetic resources for the future, comprising exploration, mobilisation, conservation, establishment, management and improvement; and
4. capacity to monitor and deliver quality seed and seedlings of multiple species required for large scale restoration.

Current planting programmes in Ethiopia are dominated by very few species of which Eucalyptus is the prominent. Overreliance on a few species in large-scale restoration is risky and

in the future use of a more diverse set of species is considered necessary to provide for both economic and ecological resilience.

The aim of PATSPO is to design a breeding programme for more than 50 priority species and to establish breeding seedling orchards (BSOs) and other types of mother blocs for a sub-set of these species. Further background information is available in the Project Document and references therein which should be consulted.

This consultancy supports the delivery of output area number 3 mentioned above.

The establishment of BSOs for tree breeding and seed procurement is an important activity of PATSPO. Ethiopia has been and are at present engaged in a number of tree improvement/ breeding and seed stand programmes/activities. Some of the older field establishments are not maintained and therefore questionable for use in ongoing and future breeding programmes, however some field establishments can be used, if some urgent maintenance are done. A PATSPO consult has prepared a status of previous and ongoing tree improvement programmes in Ethiopia, with focus on the field establishments. The consultant will assess the findings in this report and assess which programmes and field establishments can link to and be used in the PATSPO BSO breeding/seed procurement programme. The consultant will further select 1-3 species where previous programmes and the BSO programme are combined and for these species prepare detailed forward-looking breeding plans. One of the species is likely to be *Eucalyptus globulus,* and for that species, the consultant will also make a detailed plan for what genetic material to include and how it can be procured.

In addition, the consultant will follow up on work from previously visits to PATSPO related to collaboration on mother block establishment of fruit trees (Baobab, Ziziphus and Tamarind) in Kobo. Reference is made to two reports: i) Germplasm introductions of Indigenous fruit trees (baobab, tamarind & ziziphus) in Ethiopia, 2018 and ii) Establishment of breeding clonal orchards and mother blocks of indigenous fruit trees (baobab, tamarind and ziziphus) in Ethiopia, 2019.
This work included field establishments (nursery work, mother blocks and farmer plantings of the species mentioned above). The consultant will visit the field sites and assess the work and make recommendations on the continuation of this activity as well as provide training on grafting techniques to the lead staffs involved in the work at field level. This in order to produce more seedling of the improved genetic material and thereby scale up the positive impact of livelihood for farmers living in area.

2. OBJECTIVES

The primary purpose of the consultancy is to:

i) select 1-3 species where previous programmes and the BSO programme are combined and for these species prepare detailed forward-looking breeding plans.

ii) follow up on work from previously visits to PATSPO related to collaboration on mother block establishment of fruit trees (Baobab, Ziziphus and Tamarind) in Kobo.

3. METHOD OF WORK

The consultant and relevant resource persons from PATSPO (seed source officer, seed procurement officer and regional tree seed centre coordinators) will work as a team following the TOR and guidance from the Project Management Team (PMT). Most of the time will be spend in the field doing the actual layout and establishment of the mother blocs.

A briefing meeting will be held with the PATSPO staff in the beginning of the consultants two visits to Ethiopia, where the TOR will be further discussed and the itinerary for the consultancy finally decided upon. A debriefing meeting will be arranged at the end for the consultant to present the preliminary findings and conclusions for comments by the PATSPO staff.

4. OUTPUTS

Two major outputs should be produces:

A report describing forward looking breeding programmes for 1-3 priority species based on and linking the earlier breeding work done in Ethiopia and the PATSPO BSO programme.

A note describing the status of the mother block establishment of fruit trees (Baobab, Ziziphus and Tamarind) in Kobo, including training provided during the visit to the site, as well as suggestions for follow up activities to the ongoing work.

5. ACTIVITIES

The consultant will, in collaboration with the technical PATSPO staff, undertake the following specific tasks during his second visit to Ethiopia March/April 2019:

- Prepare breeding programme for 1-3 of the priority tree species of Ethiopia
- Visit the Kobo and Sirinka site and assess the status of the established mother blocks and farmer plantings.
- Provide training on grafting techniques for nursery staff and farmers involved in the mother block activities at Kobo.
- Suggest follow up activities to the ongoing work in Kobo.
- Prepare the report and note described under section four above.

6. STAFFING AND QUALITICATIONS

The team will consist of the consultant: Antoine Kalinganire, senior expert in tree breeding ICRAF, and technical PATSPO staff (seed source officer, seed procurement officer) and other PATSPO consultants. The consultant team is familiar with all aspect of tree improvement theories and have substantial field and theoretical experience.

7. TIMING AND DURATION OF THE ASSIGNMENT

The consultancy will be of 2.0 months, - 2 weeks late November 2018 and March/April 2019 of which 1-2 weeks for preparation and follow up. The remaining time will be spent in Ethiopia.

Two visits to Ethiopia is anticipated. The specific periods to be spent in Ethiopia will be decided between the consultant and PATSPO.

8. REPORTING

The consultants will, during his second visit March/April 2019, prepare and submit:

A short debriefing report/note, ref. annex 1.

One report and a note as described in section four of these ToRs.

The consultant will present and discuss the contents of the two reports with the PATSPO PMT before the two departures from Ethiopia

PATSPO will arrange for the design of the report before publishing.

9. SUPPORT FROM PATSPO

PATSPO will support the consultant and resource persons in organizing itineraries and meeting plans, as well as booking accommodation and domestic flights. Relevant background information will be made available. When in Addis Ababa the consultants will work from the ICRAF Office at the ILRI Compound.

PATSPO February 2019

Provision of Adequate Tree Seed Portfolios (PATSPO), 2017-2020

General requirements and guidelines for travel and consultancy reports

The guidelines below apply to staff of PATSPO and consultants recruited by or through PATSPO unless otherwise agreed upon.

General guidelines
PATSPO consultants should submit a debriefing note to PATSPO before the end of the stay in Ethiopia, and usually also a technical report as specified in the Terms of Reference (TOR) for the consultancy.

Debriefing note
The debriefing note is a short, typically 2-4-page note. The debriefing note should be submitted to PATSPO. Any further distribution of the report will be carried out by PATSPO and must not be done by the consultant without prior agreement.

The debriefing note should contain:

- Purpose and background of consultancy with reference to TOR in annex.
- Achievements: degree of fulfilment of TOR (outputs produced), the course of the consultancy with reference to itinerary and persons met in annexes, any problems encountered, and possible specific observations related to the consultancy.
- Follow-up: outstanding work to be done by the consultant (with reference to any deadlines in TOR), or PATSPO, and possible recommendations for additional work with relevant reference (justification) to achievements.
- General observations (optional): possible general observations and recommendations related to the project and the context of the project.

Technical reports
Technical reports can be reports covering a single well-defined technical discipline, *e.g.* infrastructure, equipment, seed source identification, seed collection/climbing, seed extraction, seed testing, seed documentation; or reports covering several disciplines, often for planning purposes, *e.g.* baseline surveys, integrated strategies, project implementation plans, seed research plans.

Reports from training courses shall include the course programme, a list of training materials used, a list of trainees, an evaluation of the achievements as considered by the participants as well as the consultant, and suggested follow-up. The evaluation should include an assessment of (i) the performance of the trainees, (ii) the quality of the training material and (iii) the need for follow-up. If considered appropriate by the consultant the debriefing note and the training course report may be combined into one.

The specific requirements of each technical report in terms of contents and deadlines for submission will usually be specified in the terms of reference. Reports must be submitted in hard-copy as well as electronic format. All rights to the outputs delivered will belong to PATSPO and the project unless otherwise agreed.

All sources of information and documentation shall be indicated and well described (literature, interview, etc.).

Often a draft report should be submitted to the project before the departure of the consultant from the project.

The cover of such reports should include the following information:

- Draft consultancy report
- Title of consultancy
- Period of consultancy
- Name of consultant (and other contributors)
- Title of project

The following standard phrase should be included in the colophon or the introduction of the report: The present report is a draft consultancy report prepared for the project. The draft is subject to review by PATSPO before finalisation.

Reports will be finalised (as final draft or final report) by the consultant according to comments and instructions given by PATSPO.

The final report will be published by PATSPO with a cover as above will contain the following standard phrase: The present report is a consultancy report prepared for and reviewed by PATSPO.

PATSPO, February 2019

Appendix 2. Itinerary for the consultancy in Ethiopia 23/4 to 17/5/2019

Date	Location	Activity	People met
22/4	Bamako	Travel to Addis-Ababa	
23/4	Addis Ababa	• Briefing meeting at ICRAF Ethiopia • Contacts for collecting scions	Soren Moestrup, Abrham Abiyu, Mekdes Sime, Girma Esthete
24/4	Adama	Travel to Melkassa Agricultural Research Center for jujube scions	Bedru Beshir, Lema Ayele
25-26/4	Addis-Ababa	• Preparation of training materials • Trip organization	
27/4	Suba	• Visit nursery for blue gum • Visit BSO of Cordia & Grevillea • Blue gum psyllid attacks	Castern Tom Norgaard, Poul Elgaard
28-30/4	Addis-Ababa	Trip organization, contacts & Training materials	Samuel Hailu, Sime Mekdes
1/5	Mekelle	• Depart Addis-Mekelle by Air • Meeting with Haile Tilahun	Haile Tilahun
2/5	Gargara	• Travel to Gargara RRC Nursery • Preparation of tree seedlings & identification	Kahnsay Geltsadik
3/5	Gargara/Maytsebri	• Travel to Maytsebri (Shire) • Transport of seedlings	
4/5	Maytsebri (TARI)	• Nursery deployment • Site selection for fruit planting	Kiros Abay, Daniel Desta
5/5	Maytsebri/Axum	Travel back to Addis-Ababa	
6/5	Melkassa	Jujube scions' collection	Girma Kebede, Asmare Dagnew, Nigusse Kebede, Lemi Negash
7/5	Sirinka	Travel Addis-Sirinka via Kompolcha	
8/5	Sirinka	Grafting course and visiting farmers	
9/5	Sirinka	• Practical grafting with trainees • Visiting lead fruit farmers	Gezahagn Getachew, Gebeyehu Alamrie, Hodaddis Kassahun, Andualem Analew, Mulukem Wudu
10/5	Kobo	Fruit Tree management	Kassa Yimer
11/5	Kobo/Addis	Travel back to Addis	
12 – 17/5	Addis	Breeding plans and reporting	

Appendix 3. People met, contacts and functions in PATSPO

Andualem Analew	Biodiversity & Conservation	Scaling-up fruit trees	0910293455
Asmare Dagnew	Horticulture Scientist	Melkassa jujube research	0911145198
Bedru Beshir	Director	Melkassa Agricultural Research Center	0911382489
Bekele Ashame	ICRAF driver &Field Assistant	Transport of Consultant in Addis Ababa	0911757176
Castern Tom Norgaard	Scientist	Consultant	
Daniel Desta	Forestry Senior Scientist	Tigray Agricultural Research Center (TARI), Director	0939648176
Gebezehu Alamrie	Agroforester, ARARI Sirinka Research Station	Supervisor of genebanks and demonstration plots	0922906518
Gezahagn Getachew	Director ARARI Sirinka Research Centre, Sirinka	Overall Supervisor of genebanks and demonstration plots	0910932003
Girma Esthete	PATSPO Project Coordinator, Awasa	Coordination of the mission, including logistics	0911817420
Girma Kebede	Fruit Research Program Coordinator, Melkassa	Melkassa jujube tree management	0911798342
Haile Tilahun	PATSPO Project Coordinator, Mekelle	Supervision of genebanks in Maytsebri (2019)	0914753302
Hodaddis Kassahun	Technician in-charge of farmers plantings	Technician in-charge of farmers plantings and follow-up	0984046181
Kahsay Geltsadik	Tree Nursery Manage at Gergera RRC	Seedlings maintenance at Gergera RRC	0919799437
Kassa Yimer	Field Manager Kobo SubStation	Observations and maintenance of genebanks at Kobo	0904683972
Kedra Mohammed	Seed Procurement Officer	Seed Procurement for BSO and Genebanks	0913919211
Kiros Abay	Forestry Scientist	Maytsebri Research Center Manager	0914040586
Lemi Negash	Technician	Vegetative propagation expert, Melkassa Agricultutural Research Center	0912312633
Lemma Ayele	Horticulture Scientist	Melkassa Agricultutural Research Center	09119912854
Mulukem Wudu	Forest conservation	Scaling-up fruit trees	0930698793
Nigusse Kebede	Field Tecnician	Melkassa jujube maintenance	0912204691
Poul Elgaard	Scientist	Consultant	
Samuel Hailu Negewo	PATSPO Project Accountant	Logistics for Consultant	0911981838
Sime Mekdes	ICRAF Administrative Officer	Facilitation of stay of Consultant	0930105749
Søren Moestrup	PATSPO Coordinator	Coordinating the consultancy	

Appendix 4. Eucalyptus globulus ssp. globulus progenies from Victoria and Tasmania, Australia

Expanded List of Quoted Seedlots

Quotation number: ATSC-15973
Date of Issue: 5/12/18

Seedlot No	Seedlot Type	Species	Tree No	No. of Parent Trees	Qty (g)	Origin							Viable Seeds/10g
						Location	State	Latitude		Longitude		Alt M	
								Deg	Min	Deg	Min		
16470	Wild	Eucalyptus globulus ssp. globulus	MG000007		10	MOOGARA	TAS	42	47	146	55	500	1343
16470	Wild	Eucalyptus globulus ssp. globulus	MG000008		12	MOOGARA	TAS	42	47	146	55	500	571
16470	Wild	Eucalyptus globulus ssp. globulus	MG000009		18	MOOGARA	TAS	42	47	146	55	500	314
16470	Wild	Eucalyptus globulus ssp. globulus	MG000011		12	MOOGARA	TAS	42	47	146	55	500	1356
16470	Wild	Eucalyptus globulus ssp. globulus	MG000012		12	MOOGARA	TAS	42	47	146	55	500	1128
16470	Wild	Eucalyptus globulus ssp. globulus	MG000013		12	MOOGARA	TAS	42	47	146	55	500	842
16470	Wild	Eucalyptus globulus ssp. globulus	MG000014		7	MOOGARA	TAS	42	47	146	55	500	1442
16470	Wild	Eucalyptus globulus ssp. globulus	MG000015		10	MOOGARA	TAS	42	47	146	55	500	656
16470	Wild	Eucalyptus globulus ssp. globulus	MG000016		12	MOOGARA	TAS	42	47	146	55	500	800
16470	Wild	Eucalyptus globulus ssp. globulus	MG000018		16	MOOGARA	TAS	42	47	146	55	500	486
16470	Wild	Eucalyptus globulus ssp. globulus	MG000019		12	MOOGARA	TAS	42	47	146	55	500	900
16470	Wild	Eucalyptus globulus ssp. globulus	MG000020		18	MOOGARA	TAS	42	47	146	55	500	600
16470	Wild	Eucalyptus globulus ssp. globulus	MG000021		17	MOOGARA	TAS	42	47	146	55	500	471
16470	Wild	Eucalyptus globulus ssp. globulus	MG000022		9	MOOGARA	TAS	42	47	146	55	500	443
16470	Wild	Eucalyptus globulus ssp. globulus	MG000023		14	MOOGARA	TAS	42	47	146	55	500	914
16470	Wild	Eucalyptus globulus ssp. globulus	MG000025		17	MOOGARA	TAS	42	47	146	55	500	600
16470	Wild	Eucalyptus globulus ssp. globulus	MG000026		16	MOOGARA	TAS	42	47	146	55	500	630
16473	Wild	Eucalyptus globulus ssp. globulus	DR000001		40	NE NEW NORFOLK	TAS	42	43	147	09	300	1157
16473	Wild	Eucalyptus globulus ssp. globulus	DR000002		40	NE NEW NORFOLK	TAS	42	43	147	09	300	899
16473	Wild	Eucalyptus globulus ssp. globulus	DR000004		60	NE NEW NORFOLK	TAS	42	43	147	09	300	271
16475	Wild	Eucalyptus globulus ssp. globulus	RD000001		40	SW OF JERICHO	TAS	42	25	147	16	500	826
16475	Wild	Eucalyptus globulus ssp. globulus	RD000004		9	SW OF JERICHO	TAS	42	25	147	16	500	1470
16475	Wild	Eucalyptus globulus ssp. globulus	RD000005		25	SW OF JERICHO	TAS	42	25	147	16	500	952
16478	Wild	Eucalyptus globulus ssp. globulus	TA000003		40	KOONYA TASMAN PEN	TAS	43	04	147	50	20	272
16478	Wild	Eucalyptus globulus ssp. globulus	TA000004		70	KOONYA TASMAN PEN	TAS	43	04	147	50	20	157
16860	Wild	Eucalyptus globulus ssp. globulus	CG001047		10	BLUE GUM SADDLE	TAS	43	13	146	55	250	560
16862	Wild	Eucalyptus globulus ssp. globulus	CG001051		30	S BRUNY ISLAND	TAS	43	21	147	18	210	914
16862	Wild	Eucalyptus globulus ssp. globulus	CG001053		30	S BRUNY ISLAND	TAS	43	21	147	18	210	742
16862	Wild	Eucalyptus globulus ssp. globulus	CG001054		18	S BRUNY ISLAND	TAS	43	21	147	18	210	942
17608	Wild	Eucalyptus globulus ssp. globulus	TR000001		5.3	KING ISLAND	TAS	39	56	143	52	40	1071
17608	Wild	Eucalyptus globulus ssp. globulus	TR000004		6	KING ISLAND	TAS	39	56	143	52	40	1029
17608	Wild	Eucalyptus globulus ssp. globulus	TR000006		7	KING ISLAND	TAS	39	56	143	52	40	1529
17608	Wild	Eucalyptus globulus ssp. globulus	TR000032		40	KING ISLAND	TAS	39	56	143	52	40	557
17695	Wild	Eucalyptus globulus ssp. globulus	LV000002		5.2	SW OF HOBART	TAS	42	58	147	14	250	1057
17799	Wild	Eucalyptus globulus ssp. globulus	TREE02		45	FLINDERS ISLAND	TAS	40	06	148	00	15	1040
17799	Wild	Eucalyptus globulus ssp. globulus	TREE04		60	FLINDERS ISLAND	TAS	40	06	148	00	15	420
17799	Wild	Eucalyptus globulus ssp. globulus	TREE06		40	FLINDERS ISLAND	TAS	40	06	148	00	15	860
18025	Wild	Eucalyptus globulus ssp. globulus	CH1		17	MIDDLETON	TAS	43	13	147	15	5	385
18025	Wild	Eucalyptus globulus ssp. globulus	CH2		15	MIDDLETON	TAS	43	13	147	15	5	385
18032	Wild	Eucalyptus globulus ssp. globulus	G1		12	GEEVESTON AREA	TAS	43	13	146	54	360	857
18032	Wild	Eucalyptus globulus ssp. globulus	G2		15	GEEVESTON AREA	TAS	43	13	146	54	360	314
18032	Wild	Eucalyptus globulus ssp. globulus	G3		18	GEEVESTON AREA	TAS	43	13	146	54	360	490
18032	Wild	Eucalyptus globulus ssp. globulus	G4		11	GEEVESTON AREA	TAS	43	13	146	54	360	928
18032	Wild	Eucalyptus globulus ssp. globulus	G6		20	GEEVESTON AREA	TAS	43	13	146	54	360	885

18032	Wild	Eucalyptus globulus ssp. globulus	G7		14	GEEVESTON AREA	TAS	43	13	146	54	360	428
18032	Wild	Eucalyptus globulus ssp. globulus	G8		20	GEEVESTON AREA	TAS	43	13	146	54	360	942
18032	Wild	Eucalyptus globulus ssp. globulus	G9		14	GEEVESTON AREA	TAS	43	13	146	54	360	400
18033	Wild	Eucalyptus globulus ssp. globulus	L2		16	LONNAVULE	TAS	42	58	146	44	300	442
18033	Wild	Eucalyptus globulus ssp. globulus	L3		14	LONNAVULE	TAS	42	58	146	44	300	542
18673	Wild	Eucalyptus globulus ssp. globulus	CH13		20	CRADOC HILL	TAS	43	07	147	05	250	700
18673	Wild	Eucalyptus globulus ssp. globulus	CH14		17	CRADOC HILL	TAS	43	07	147	05	250	350
18673	Wild	Eucalyptus globulus ssp. globulus	CH15		16	CRADOC HILL	TAS	43	07	147	05	250	336
18673	Wild	Eucalyptus globulus ssp. globulus	CH16		17	CRADOC HILL	TAS	43	07	147	05	250	364
18673	Wild	Eucalyptus globulus ssp. globulus	CH17		18	CRADOC HILL	TAS	43	07	147	05	250	896
18673	Wild	Eucalyptus globulus ssp. globulus	CH18		17	CRADOC HILL	TAS	43	07	147	05	250	630
18673	Wild	Eucalyptus globulus ssp. globulus	CH19		17	CRADOC HILL	TAS	43	07	147	05	250	350
18673	Wild	Eucalyptus globulus ssp. globulus	CH2		18	CRADOC HILL	TAS	43	07	147	05	250	742
18673	Wild	Eucalyptus globulus ssp. globulus	CH22		16	CRADOC HILL	TAS	43	07	147	05	250	294
18673	Wild	Eucalyptus globulus ssp. globulus	CH5		10	CRADOC HILL	TAS	43	07	147	05	250	756
18673	Wild	Eucalyptus globulus ssp. globulus	CH8		9	CRADOC HILL	TAS	43	07	147	05	250	770
18673	Wild	Eucalyptus globulus ssp. globulus	CH9		12	CRADOC HILL	TAS	43	07	147	05	250	574
18707	Wild	Eucalyptus globulus ssp. globulus	FL13		9	FLINDERS ISLAND	TAS	40	07	148	01	20	2086
18707	Wild	Eucalyptus globulus ssp. globulus	FL15		13	FLINDERS ISLAND	TAS	40	07	148	01	20	434
18707	Wild	Eucalyptus globulus ssp. globulus	FL17		8	FLINDERS ISLAND	TAS	40	07	148	01	20	1806
18707	Wild	Eucalyptus globulus ssp. globulus	FL18		12	FLINDERS ISLAND	TAS	40	07	148	01	20	826
18707	Wild	Eucalyptus globulus ssp. globulus	FL20		13.2	FLINDERS ISLAND	TAS	40	07	148	01	20	420
18707	Wild	Eucalyptus globulus ssp. globulus	FL23		13	FLINDERS ISLAND	TAS	40	07	148	01	20	518
18707	Wild	Eucalyptus globulus ssp. globulus	FL24		11	FLINDERS ISLAND	TAS	40	07	148	01	20	770
18707	Wild	Eucalyptus globulus ssp. globulus	FL25		13	FLINDERS ISLAND	TAS	40	07	148	01	20	560
18707	Wild	Eucalyptus globulus ssp. globulus	FL29		11	FLINDERS ISLAND	TAS	40	07	148	01	20	728
18707	Wild	Eucalyptus globulus ssp. globulus	FL37		11	FLINDERS ISLAND	TAS	40	07	148	01	20	868
18707	Wild	Eucalyptus globulus ssp. globulus	FL39		10	FLINDERS ISLAND	TAS	40	07	148	01	20	728
18707	Wild	Eucalyptus globulus ssp. globulus	FL40		12	FLINDERS ISLAND	TAS	40	07	148	01	20	1092
18707	Wild	Eucalyptus globulus ssp. globulus	FL44		11	FLINDERS ISLAND	TAS	40	07	148	01	20	1134
18707	Wild	Eucalyptus globulus ssp. globulus	FL45		8.5	FLINDERS ISLAND	TAS	40	07	148	01	20	1386
18707	Wild	Eucalyptus globulus ssp. globulus	FL5		13	FLINDERS ISLAND	TAS	40	07	148	01	20	406
18708	Wild	Eucalyptus globulus ssp. globulus	T19		4.9	OTWAYS SF &YUULONG	VIC	38	42	143	33	250	854
18708	Wild	Eucalyptus globulus ssp. globulus	T2		4.9	OTWAYS SF &YUULONG	VIC	38	42	143	33	250	980
18708	Wild	Eucalyptus globulus ssp. globulus	T49		4.7	OTWAYS SF &YUULONG	VIC	38	42	143	33	250	1036
18708	Wild	Eucalyptus globulus ssp. globulus	T50		5.3	OTWAYS SF &YUULONG	VIC	38	42	143	33	250	1162
18708	Wild	Eucalyptus globulus ssp. globulus	Y16		4.9	OTWAYS SF &YUULONG	VIC	38	42	143	33	250	1400
18723	Wild	Eucalyptus globulus ssp. globulus	GD1		20	GEEVESTON	TAS	43	15	146	59	110	214
18723	Wild	Eucalyptus globulus ssp. globulus	GD13		26	GEEVESTON	TAS	43	15	146	59	110	242
18723	Wild	Eucalyptus globulus ssp. globulus	GD14		30	GEEVESTON	TAS	43	15	146	59	110	199
18723	Wild	Eucalyptus globulus ssp. globulus	GD15		21	GEEVESTON	TAS	43	15	146	59	110	228
18723	Wild	Eucalyptus globulus ssp. globulus	GD17		36	GEEVESTON	TAS	43	15	146	59	110	171
18723	Wild	Eucalyptus globulus ssp. globulus	GD19		37	GEEVESTON	TAS	43	15	146	59	110	114
18723	Wild	Eucalyptus globulus ssp. globulus	GD4		30	GEEVESTON	TAS	43	15	146	59	110	357
18723	Wild	Eucalyptus globulus ssp. globulus	GD5		19	GEEVESTON	TAS	43	15	146	59	110	228
18724	Wild	Eucalyptus globulus ssp. globulus	MG14		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG15		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG16		16	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG17		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG18		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG19		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG3		27	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG4		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG6		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG7		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG8		20	MOOGARA	TAS	42	48	146	53	540	714
18724	Wild	Eucalyptus globulus ssp. globulus	MG9		20	MOOGARA	TAS	42	48	146	53	540	714
18881	Wild	Eucalyptus globulus ssp. globulus	CG2618		16	OTWAY NATIONAL PARK	VIC	38	48	143	37	150	490

18881	Wild	Eucalyptus globulus ssp. globulus	CG2620		9	OTWAY NATIONAL PARK	VIC	38	48	143	37	150	504
18883	Wild	Eucalyptus globulus ssp. globulus	CG2628		20	W OF GLENAIRE	VIC	38	46	143	25	100	616
18888	Wild	Eucalyptus globulus ssp. globulus	CG2659		50	NORTH OF YARRAM	VIC	38	22	146	41	480	532
18889	Wild	Eucalyptus globulus ssp. globulus	CG2671		10	BLUE GUM SADDLE	TAS	43	12	146	54	250	799
18891	Wild	Eucalyptus globulus ssp. globulus	CG2697		13	STORM HILL ROAD	TAS	43	17	146	58	340	518
18891	Wild	Eucalyptus globulus ssp. globulus	CG2698		13	STORM HILL ROAD	TAS	43	17	146	58	340	658
18891	Wild	Eucalyptus globulus ssp. globulus	CG2700		11	STORM HILL ROAD	TAS	43	17	146	58	340	560
18891	Wild	Eucalyptus globulus ssp. globulus	CG2701		14	STORM HILL ROAD	TAS	43	17	146	58	340	1134
18891	Wild	Eucalyptus globulus ssp. globulus	CG2705		12	STORM HILL ROAD	TAS	43	17	146	58	340	420
18891	Wild	Eucalyptus globulus ssp. globulus	CG2707		13.3	STORM HILL ROAD	TAS	43	17	146	58	340	546
18891	Wild	Eucalyptus globulus ssp. globulus	CG2709		13	STORM HILL ROAD	TAS	43	17	146	58	340	770
18891	Wild	Eucalyptus globulus ssp. globulus	CG2710		14	STORM HILL ROAD	TAS	43	17	146	58	340	868
18892	Wild	Eucalyptus globulus ssp. globulus	CG2714		60	HOPETOUN ROAD	TAS	43	16	146	59	280	504
18892	Wild	Eucalyptus globulus ssp. globulus	CG2715		40	HOPETOUN ROAD	TAS	43	16	146	59	280	406
18892	Wild	Eucalyptus globulus ssp. globulus	CG2716		40	HOPETOUN ROAD	TAS	43	16	146	59	280	196
18892	Wild	Eucalyptus globulus ssp. globulus	CG2717		50	HOPETOUN ROAD	TAS	43	16	146	59	280	168
18893	Wild	Eucalyptus globulus ssp. globulus	CG2718		60	WIELANGTA SF	TAS	42	44	147	53	310	504
18893	Wild	Eucalyptus globulus ssp. globulus	CG2719		50	WIELANGTA SF	TAS	42	44	147	53	310	476
18893	Wild	Eucalyptus globulus ssp. globulus	CG2721		50	WIELANGTA SF	TAS	42	44	147	53	310	224
18895	Wild	Eucalyptus globulus ssp. globulus	CG2730		20	SW OF JERICHO	TAS	42	25	147	16	500	271
18895	Wild	Eucalyptus globulus ssp. globulus	CG2731		20	SW OF JERICHO	TAS	42	25	147	16	500	357
18895	Wild	Eucalyptus globulus ssp. globulus	CG2733		19	SW OF JERICHO	TAS	42	25	147	16	500	457
18895	Wild	Eucalyptus globulus ssp. globulus	CG2735		19	SW OF JERICHO	TAS	42	25	147	16	500	242
18895	Wild	Eucalyptus globulus ssp. globulus	CG2736		12	SW OF JERICHO	TAS	42	25	147	16	500	1128
18895	Wild	Eucalyptus globulus ssp. globulus	CG2737		18	SW OF JERICHO	TAS	42	25	147	16	500	442
18895	Wild	Eucalyptus globulus ssp. globulus	CG2738		15	SW OF JERICHO	TAS	42	25	147	16	500	528
18895	Wild	Eucalyptus globulus ssp. globulus	CG2739		14	SW OF JERICHO	TAS	42	25	147	16	500	885
19161	Wild	Eucalyptus globulus ssp. globulus	T1		7.8	FLINDERS IS	TAS	40	07	148	01	90	952
19161	Wild	Eucalyptus globulus ssp. globulus	T10		8	FLINDERS IS	TAS	40	07	148	01	90	1008
19161	Wild	Eucalyptus globulus ssp. globulus	T11		9	FLINDERS IS	TAS	40	07	148	01	90	1148
19161	Wild	Eucalyptus globulus ssp. globulus	T12		8	FLINDERS IS	TAS	40	07	148	01	90	924
19161	Wild	Eucalyptus globulus ssp. globulus	T14		9	FLINDERS IS	TAS	40	07	148	01	90	1036
19161	Wild	Eucalyptus globulus ssp. globulus	T19		7.7	FLINDERS IS	TAS	40	07	148	01	90	1008
19161	Wild	Eucalyptus globulus ssp. globulus	T2		9	FLINDERS IS	TAS	40	07	148	01	90	1120
19161	Wild	Eucalyptus globulus ssp. globulus	T24		6.7	FLINDERS IS	TAS	40	07	148	01	90	910
19161	Wild	Eucalyptus globulus ssp. globulus	T25		3.7	FLINDERS IS	TAS	40	07	148	01	90	1834
19161	Wild	Eucalyptus globulus ssp. globulus	T27		5	FLINDERS IS	TAS	40	07	148	01	90	1988
19161	Wild	Eucalyptus globulus ssp. globulus	T34		6.7	FLINDERS IS	TAS	40	07	148	01	90	798
19161	Wild	Eucalyptus globulus ssp. globulus	T36		6.8	FLINDERS IS	TAS	40	07	148	01	90	1120
19161	Wild	Eucalyptus globulus ssp. globulus	T37		7	FLINDERS IS	TAS	40	07	148	01	90	1540
19161	Wild	Eucalyptus globulus ssp. globulus	T38		7	FLINDERS IS	TAS	40	07	148	01	90	1358
19161	Wild	Eucalyptus globulus ssp. globulus	T4		2.9	FLINDERS IS	TAS	40	07	148	01	90	1820
19161	Wild	Eucalyptus globulus ssp. globulus	T6		9	FLINDERS IS	TAS	40	07	148	01	90	1554
19161	Wild	Eucalyptus globulus ssp. globulus	T8		8	FLINDERS IS	TAS	40	07	148	01	90	1092
21182	Wild	Eucalyptus globulus ssp. globulus	JL081		6.8	JEERALANGS	VIC	38	19	146	24	179	700
21182	Wild	Eucalyptus globulus ssp. globulus	JL082		4	JEERALANGS	VIC	38	19	146	24	179	1722
21182	Wild	Eucalyptus globulus ssp. globulus	JL086		7	JEERALANGS	VIC	38	19	146	24	179	1060
21182	Wild	Eucalyptus globulus ssp. globulus	JL088		5	JEERALANGS	VIC	38	19	146	24	179	1680
21182	Wild	Eucalyptus globulus ssp. globulus	JL089		5	JEERALANGS	VIC	38	19	146	24	179	1680
21182	Wild	Eucalyptus globulus ssp. globulus	JL091		7.2	JEERALANGS	VIC	38	19	146	24	179	740
21182	Wild	Eucalyptus globulus ssp. globulus	JL092		8	JEERALANGS	VIC	38	19	146	24	179	1000
21182	Wild	Eucalyptus globulus ssp. globulus	JL094		4.5	JEERALANGS	VIC	38	19	146	24	179	1440
21182	Wild	Eucalyptus globulus ssp. globulus	JL095		4	JEERALANGS	VIC	38	19	146	24	179	1880
21182	Wild	Eucalyptus globulus ssp. globulus	JL099		7	JEERALANGS	VIC	38	19	146	24	179	740
21182	Wild	Eucalyptus globulus ssp. globulus	JL100		8	JEERALANGS	VIC	38	19	146	24	179	740
21182	Wild	Eucalyptus globulus ssp. globulus	JL102		8	JEERALANGS	VIC	38	19	146	24	179	580
21182	Wild	Eucalyptus globulus ssp. globulus	JL104		6	JEERALANGS	VIC	38	19	146	24	179	1260
21182	Wild	Eucalyptus globulus ssp. globulus	JL105		5	JEERALANGS	VIC	38	19	146	24	179	1840

21182	Wild	Eucalyptus globulus ssp. globulus	JL106		5	JEERALANGS	VIC	38	19	146	24	179	1680
21182	Wild	Eucalyptus globulus ssp. globulus	JL107		5	JEERALANGS	VIC	38	19	146	24	179	1280
21182	Wild	Eucalyptus globulus ssp. globulus	JL111		4	JEERALANGS	VIC	38	19	146	24	179	1860
21182	Wild	Eucalyptus globulus ssp. globulus	JL115		4	JEERALANGS	VIC	38	19	146	24	179	2400
21182	Wild	Eucalyptus globulus ssp. globulus	JL122		6	JEERALANGS	VIC	38	19	146	24	179	840

PATSPO

Provision of adequate tree seed portfolios

World Agroforestry Centre

PATSPO/ICRAF Office
c/o ILRI Campus, Gurd Shola, P.O. Box 5689,
Addis Ababa, Ethiopia

Phone: 251-116172000
ext. 2491
Email:K.Hadgu@cgiar.org

Website: https://www.worldagroforestry.org/project/provision-adequate-tree-seed-portfolio-ethiopia