

## **Conservation and genetic improvement in the Northern Territory (Australia) of *Khaya senegalensis* (African mahogany) - a valuable tree species endangered in parts of its homelands**

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### **Summary**

*Khaya senegalensis*, a high-value hardwood timber species, was first planted in the Northern Territory (NT) more than 40 years ago. Stands established in the 1960s-1970s remain near Gunn Point, Howard Springs, other places in the NT, and also at Weipa, Queensland. There are widespread, mostly small plantings of the 1990s in the NT and east-central Queensland, and more recent ones in the latter region. The species is well adapted and fast growing in many plantings, and it has a vast homocline across northern Australia. Trees salvaged in the NT (from street, park and home-site plantings), and harvested from stands there and at Weipa, give high quality wood from which award-winning, specialty furniture and other valuable products have been made.

The species appears to have the potential to underpin a forestry industry in northern Australia. However, the early plantings, which were all of genetically-unimproved planting stock, contain many trees with short, crooked boles. This is also the case in the young plantings derived from seed from the old stands, amenity trees or importation without any effective, local selection. The unavailability of genetically-improved planting stock is a potential constraint on the optimal development of a forestry industry in northern Australia based on *K. senegalensis*.

In 2001, a program of conservation and genetic improvement, from the substantial sample of the species in first-base stands planted in the Darwin region in the 1970s, was commenced. It involved mild selection of trees with 'acceptable' relative vigour, straightness, bole length and branching. In all, 24 provenances from 11 countries of nativity between Senegal and Uganda, plus one secondary and some unknown sources (some 7 ha, all threatened) were sampled. Other achievements include:

- a) Documentation of short- and long-term strategic plans in 2003;
- b) Establishment of 142 grafted clones in both a 'gene recombination orchard' (GRO) and a conservation clone bank (CCB) in 2002-2004 to generate progeny with great diversity (limited flowering occurred in 2004), and ensure protection of the selected germplasm;
- c) Rooting of cuttings in 2004 of more than 400 hedged seedlings (from some 20 select trees) and coppice (from select-tree stumps) for planting first clone tests on 3 sites in 2005;
- d) Congregation in 2004 of grafts of the seemingly-best 14/142 clones at one end of the CCB to promote production of seed from them to raise plants for a second series of clone tests; and
- e) Selection of a site in 2004 for a clonal seed orchard needed to allow a future option of establishing stands via seed or seedlings.

Planting a second-cycle, base population is planned to follow procurement of seed from individual clones in the GRO (after the first heavy, general flowering), and from infusions. This should enable future selection of second-generation and some infused trees for on-going improvement. Imperatives and research and development (R&D) needs for further development of the program are suggested.

## Introduction

*Khaya senegalensis* Desr. (A. Juss.) (African mahogany) is a high-value hardwood (HVH) timber species indigenous in the monsoonal tropics of west-central Africa from Senegal to Sudan and Uganda. It has been logged there commercially for nearly 200 years because of the value of its timber, which resembles that of a cohort species of the same family, Meliaceae, the famed American mahogany *Swietenia macrophylla* King (Anon. 2004).

*K. senegalensis* was introduced in the Northern Territory (NT) more than 40 years ago and is a conspicuous tree in many landscapes in the Darwin to Katherine regions and beyond. Stands planted in the 1970s remain in the former Gunn Point Forestry Reserve (referred to below as 'near Gunn Point'), near Howard Springs, other places in the NT, and at Weipa, Queensland. These old stands generally have very high survivals today. Although these stands have never been thinned, they contained merchantable trees by less than 30 years of age. Small stands up to 15 years of age in the Burdekin region in Queensland also exhibit impressive survival and growth (Dickinson et al. 2004). Clearly, the species is widely adapted. It can be fast growing in a range of conditions in northern Australia. However, all these stands, plots of young trees in NT trials described by Reilly et al. 2004, and a 2001 planting from imported seed at Walkamin, Queensland, are characterised by high proportions of trees with crooked, short boles.

Trees salvaged in the Darwin and Katherine areas (from street, park and home-site plantings), and harvested at Weipa, give high quality wood, evidenced by the good market for their products (Whitbread, 2003). Several, selected, in-stand, 30-year-old NT trees have given good yields of timber and high-quality, specialty products (Armstrong et al. 2004).

In 2000, it was realised by the senior author (during a visit with the co-authors and K. Robson) that the germplasm in provenance trials planted near Gunn Point in the early 1970s (see below for details) probably represented a substantial sample of the genetic resources of the species, and that they were under threat of loss from fire, illegal removal of trees and potential redevelopment of the land. As well, it appeared the species was promising for agroforestry and other commercial planting purposes in the NT and north Queensland, especially if stem straightness and bole length could be improved. Consequently, it was agreed to include in a project that had already been established between the Agroforestry group of the then NT Department of Primary Industries and Fisheries, the then Queensland Forestry Research Institute and the Rural Industries Research and Development Corporation, Joint Venture Agroforestry Program (RIRDC, JVAP), the funding of initiation of conservation and genetic improvement with the species. Work under that program commenced in 2001 and continued until 2003 (Reilly et al. in press). Following completion of the RIRDC project in 2003, the work with *K. senegalensis* has been continued by the NT Agroforestry group (within the now Department of Business, Industry and Resource Development - DBIRD) with guidance from the senior author of the present paper (Nikles et al. 2004).

This paper provides background information on the species, gives some justification for the program and the strategy adopted, and reports progress on implementation of the strategy.

## Natural distribution and some implications for plantings in Australia

According to the Forestry Compendium (Anon. 2004), *K. senegalensis* has a wide, intermittent, natural distribution in 19 African countries (however, Egypt was erroneously included in the list) within a belt stretching from Senegal-Ivory Coast in the west to Uganda and southern Sudan towards the east. Eyog-Matig 1987 mentions its occurrence in Burkina Faso as well. According to an approximate distribution map provided by Dr Antoine Kalinginaire of the World Agroforestry Centre to Roger Arnold and presented in Arnold et al. 2004, it can be seen that:

- a) There appears to be a major disjunction in the distribution of *K. senegalensis* over a wide area from western Nigeria eastwards to eastern Cameroon.
- b) The species may have its greatest areas of occurrence in two regions – a western one from Senegal to Benin; and another, east of the disjunction, principally in the Central African Republic, but including parts of Cameroon, Sudan and Uganda.
- c) The species may have only relatively minor occurrences in Cameroon, Chad, Mauritania, Niger, Nigeria, Sierra Leone, Sudan and Uganda.

The species ranges approximately between 8<sup>o</sup> and 15<sup>o</sup> N and from sea level to 1,800 m, encompassing mean annual rainfalls from 700 mm to 1,750 mm with dry season lengths from 2 to 8 months (Anon. 2004). It inhabits a wide variety of sites and soil types though it 'prefers moist sites, such as depressions and the banks of rivers and streams' (gallery forest, mixed species), rather than drier 'open savanna with lateritic soils (ferrosols)', where it often occurs as solitary trees (Anon. 2004).

In view of the wide range of geographic, climatic, altitudinal and edaphic/physiographic conditions over the natural distribution of *K. senegalensis*, and the intermittent natural occurrences within its two major geographic regions, much provenance variation would be expected across the species, as well as within-provenance variation (Zobel et al. 1987). This augurs well for anticipated plantings in Australia, provided a wide genetic base is employed in its domestication here, as it should then be possible, ultimately, to mould and match germplasm to locations and sites.

The high adaptability of the material introduced so far, even, is demonstrated by the high survival and good growth of the species in a wide range of conditions in the NT and Queensland, as indicated above. Furthermore, it is well known that many tree species adapt and grow well, especially as exotics, in conditions of climate and soil somewhat outside those of their natural ranges. In respect to climates, and early growth in trials in several regions in northern Australia, *K. senegalensis* is predicted to have a vast homoclimate and extensive areas suitable for good early growth at least in the sub-continent (Arnold et al. 2004). Thus it is anticipated there are many areas in northern Australia where the species could be grown commercially.

### **Status of the native genetic resources**

A summary of the status of the genetic resources of the world's most important forest tree species is contained in the FAO world-wide information system REFORGEN 2004 (currently being revised). This database shows the conservation status of *K. senegalensis* is considered endangered in all 13 listed countries of its natural occurrence in central, west-east Africa. [The species actually occurs naturally in several additional countries, as mentioned above, and it is likely to have the same conservation status (endangered) there]. REFORGEN 2004 also shows that few well-designed provenance trials (which can serve as conservation areas) are established anywhere in the world (data from a 1993 survey). Trials including substantial numbers of provenances are listed for Burkina Faso and Nigeria only, but no details of the provenances included, nor results of these trials, seem to have been published. [Updating of the information on conservation and tree improvement is in progress (pers. comm., P. Sigaud, FAO, 2004)].

### **Genetic resources established in the Northern Territory and Queensland**

By the late 1960s the potential of the species in the NT was judged sufficiently promising to warrant establishment of trials aimed at securing information and developing methodologies that would enable successful plantations to be established. Consequently, a number of research trials with *K. senegalensis* were planted in the Darwin region and on Melville Island in the early 1970s by CSIRO, that included investigations of nutrition, espacement, planting stock type, provenance variation and other related matters (Cameron 1985). The provenance trials incorporated 21 provenances from 11

countries of nativity and 3 from a secondary source (New Caledonia); and some other plantings were made with stock from local sources of unknown original provenance (Table 1).

Some genetic resources of *K. senegalensis* have been or are being accumulated in north and east-central Queensland at Weipa (Bragg et al. 2004), Walkamin Research Station (unpubl. records, DPI and F, Horticulture and Forestry Science); in extensive agroforestry plantings in the Bowen to Townsville region (Dickinson et al. 2004) and Rollingsstone area (pers. comm., G. Dickinson 2004); and via seed importations by promoters of managed investment schemes (MISs) for intended plantings in the Cooktown, Lakeland and Burdekin regions (Jago 2004, pers. comms. G. Sexton 2004 and M. Bell 2004). Included in the resources at Walkamin are grafts of 68 trees of the first, NT breeding population (see below) to add to the security of conservation of that material.

## Provenance and other genetic variation

In many tree species, provenance variation is so great that important increases in plantation production and profitability can be achieved simply by identifying and deploying the best provenance or provenances (Eldridge et al. 1994, Zobel et al. 1987). Furthermore, it is obviously optimal to begin a population improvement program of tree breeding with the best provenance/s, or to infuse them as soon as possible. Therefore, it is important to determine provenance variation of *K. senegalensis*.

Unfortunately, provenance variation of *K. senegalensis* is not documented, and possibly not yet studied effectively, as Anon. 2004 has no record of published works in this field, neither under 'Variation and breeding' nor 'References'. Similarly, the Agroforestry Database of the CGIAR's World Agroforestry Centre (formerly ICRAF) (WAC 2004) contains no information on genetic variation of *K. senegalensis*. The limited reference to provenance evaluation in REFORGEN 2004 has been mentioned above.

Over 3 successive planting seasons during 1970/71 to 1972/73, variable numbers of provenances were planted in the NT in adjacent areas near Gunn Point approximately 45 km NE of Darwin and at Tuyu, Melville Is. (Table 1). Trials comprised plots of 49 trees (7 rows x 7 trees with trees spaced at 3 m x 3 m) in randomised complete block designs with 2 to 4 replications. Although provenances are documented by country of origin and an identification number, there are no records available now of precise origins of the seed in most cases, nor of numbers of parent trees represented in the collections. The trees planted at Tuyu on Melville Is. developed very poorly for unknown reasons. None of the mainland or other trials could be managed in any way after Cyclone Tracy in 1974.

Data gathered comprised annual survival counts and height measures up to only 2.5 years of age; and from the trials near Gunn Point only, diameter and predominant height at ages around 29 years. Interpretation of trial results is compromised, however, because stock age, size and type (tubed, open root) and time of planting could not be uniform within trials. As well, recent inspection suggests there is considerable site variation within blocks, and variable survival up to the times of the measures at around 29 years would have influenced diameter growth. The mean heights were determined from quite small numbers of trees. Stem straightness and bole length were not assessed but, in careful searching of the provenance trials, and all other NT stands during 2001 to 2003, for superior trees to form a conservation and breeding population (see below under '**Selection and distribution of superior trees...resources**'), there appeared to be large and random variation in these traits, with crooked, short boles predominating.

A recent examination by the senior author of the data available of individual replicate means for common stock types within trials revealed high early survivals, but a strong tendency for ranked means for growth to vary greatly across replicates. However, there was some evidence that high-performing provenances at early and later ages may be found in disparate parts of the natural distribution; there appeared to be a slight tendency for several provenances of the western sector of

natural occurrence to have greater growth rate; and some secondary provenances from New Caledonia performed very poorly (possibly due to hypothesised greater inbreeding).

Although a more stringent analysis, for example employing covariates, might provide some reliable rankings of provenance potential, it appears that the utility of information from the NT trials is very limited.

Additionally, the well-developed trials were located near Gunn Point only, where the near-maritime climatic and edaphic environments differ markedly from those of at least one other region in the NT (Katherine), and perhaps Queensland, where the species has considerable early potential (Reilly et al. 2004 re Katherine; and Dickinson et al. 2004 re Queensland), and could be future targets for commercial plantings. So results from the trials near Gunn Point might not be a good predictor of provenance potential elsewhere.

No information is available demonstrating genetic variation in economic traits at the levels of family or individual. However, important variation at these levels can be expected in this species in view that genetic variation within provenances is commonly found (eg. in eucalypts – Eldridge et al. 1994). Observations in the old stands and the young trials described by Reilly et al. 2004, showed great phenotypic variation in tree height, diameter, branching and bole length; and stem straightness showed some variation about a low average. We have also observed considerable genetic variation between grafted clones (establishment described below) in leaf morphology, branching and propensity to flower at an early age.

It is clear from points made in the above sections that genetic variation among and within provenances of *K. senegalensis* is virtually undetermined; it can be expected to be large; it needs to be studied thoroughly; and infusions of new germplasm almost certainly need to be made - if extensive plantings of the species are contemplated for Australia.

### **Why undertake conservation and genetic improvement of *K. senegalensis* in the NT?**

The species is probably the most promising high-value hardwood timber species available for planting in parts of the Northern Territory and north Queensland. The following evidence attests this:

- a) There are favourable reports in papers to this Workshop (Armstrong et al. 2004; Arnold et al. 2004; Bragg et al. 2004; Dickinson et al. 2004, Reilly et al. 2004).
- b) It has been chosen by the NT Government's DBIRD for promotion as the basis of a HVH plantation industry (Whitbread 2003).
- c) It is the species favoured by promoters of MISs for plantings in north Queensland (Jago 2004, pers comms. G. Sexton 2004 and M. Bell 2004).
- d) The species grows to commercial sizes, including in unthinned stands, in areas in the NT (Armstrong et al. 2004, Whitbread 2003) and Weipa, Queensland (Bragg et al. 2004), although average stem straightness and bole length are poor.
- e) Near Gunn Point and Howard Springs the tallest trees at 30 years of age in the unthinned stands were 28 m and 25 m respectively, and many were merchantable at younger ages; and the stands exhibit high survival.

Although the species often occurs as solitary trees in savanna woodland in Africa (Anon. 2004), it is well-adapted to growing in very-heavily-stocked, planted stands in the NT. For example, it is remarkable that, at Howard Springs, survival is very high (average of 91% across 2 random, interior, sample plots, each of 100 planted positions) at age 34.5 years in an experiment (EP 340) occupying 0.40 ha that was planted at 4 440 spha and never thinned.

The species has many favourable silvicultural characteristics in research and other plantings in northern Australia or SE and east-central Queensland trials including:

- a) When well established, it tolerates mild fire, drought, termites, fairly strong winds and flooding (Reilly et al. 2004).
- b) It is less susceptible to shoot borer (*Hypsipyla robusta* Moore) at a SE Queensland site than at least 4 other Meliaceae species (in decreasing order of susceptibility: *Toona ciliata*, *Swietenia macrophylla*, *Chuckrasia tabularis* and *Cedrela odorata*) (Griffiths et al. 2004), a finding supported by results of work elsewhere (da Silva et al., 2004);
- c) It seeds locally, seed can be stored (Jøker and Gaméné, 2003), and the species can be readily propagated vegetatively via grafting and rooting of cuttings (information in this paper); and
- d) It responds well to irrigation, fertiliser and pruning at Weipa, near Darwin and in east-central Queensland (Bevege 1974, Cameron 1985, Dickinson et al. 2004).

Although stem straightness and bole length are generally poor, there is variation (apparently random within provenances) for these traits such that careful selection and breeding, especially with clonal and progeny testing, is likely to realise great improvement. This has been achieved with many other forest tree species, for example with a native and several introduced pines in Queensland (Nikles 1996).

Arnold et al. 2004 show that the species has a vast homoclimate across northern Australia. Therefore, it should be possible to select areas for its deployment to plantings such that high survival and good growth ensue where good planting stock and management are applied.

In addition, the capacity of the species to produce high-value products from trees grown in northern Australia has been demonstrated. Several, 30- to 32-years-old trees (rotation age or older) among 38 sampled, in stands planted in the NT in the early 1970s with genetically-unimproved stock, have given high green-off-saw recoveries, timber with good properties for high-value products, and award-winning, specialty furniture (Armstrong et al. 2004). The species produces timber of high quality at Weipa, Queensland (Bragg et al. 2004), and from trees grown near Katherine, NT (Whitbread, 2003).

Furthermore, timber from *K. senegalensis* plantations could replace some of the volumes of other high-value species being logged unsustainably from some natural forests overseas.

### **Selection and distribution of superior trees and need for extra genetic resources**

A start was made on the selection of superior trees in the NT in July 2001. The aim was to select the best 5 trees in each provenance, and additional good trees where available. Selection criteria were high relative growth, good stem straightness, large bole length and good branching. The distribution among countries of origin of the 142 trees selected is given in Table 2. Commonly, around 4-6 trees were selected per provenance. The low numbers of selects per provenance for Benin and Chad (2 and 3) reflected the difficulty in finding acceptable trees in the very poorly developed stands at Tuyu on Melville Is., the only place where plots of these origins had been planted.

The average rate of selection of trees for the breeding population (142 from c. 7 ha of plantings) was a mild 1 in 50 (approximately), reflecting the aim to conserve widely, and the small area of plantings available for screening. This initial conservation and breeding population of 142 trees is rather lower in number than the desirable census number for a long-term breeding program, considering suggestions by White 1992, viz. “a few hundred to 1,000 members may be warranted for some programs, and many advanced-generation programs have breeding populations with census numbers around 300”. Thus, for a long-term program with *K. senegalensis* in the NT, consideration will need to be given to broadening the base. This will be essential if the initial breeding population is found to incorporate considerable co-ancestry, as can be expected within groups of select trees of the same

provenance that may derive from very few seed parents. (The urgency of such broadening of the base will be lessened if there is very extensive crossing between clones of different provenances in the gene recombination orchard (GRO) that has been established in the NT – see below under '**Initial strategy for conservation... in the NT**').

Although insufficient details of the natural distribution of the species are available, the inventory of origins of NT breeding population trees (Table 2) suggests some parts of the broad range of the species (Arnold et al. 2004) are much better represented than other parts. Relatively well represented are the far north west (Senegal – 36 selects from 4 provenances); the southern part of a west-central region from Ivory Coast to and including Nigeria (48 selects from 8 provenances in 6 countries); and the far eastern extremity (28 selects from 6 provenances in Sudan and Uganda). The species appears to occur extensively in the Central African Republic (CAR), but this land-locked country is very poorly represented by germplasm in the NT (6 selects from one provenance). It would seem very desirable to secure additional seed collections from the CAR, and from neighbouring Cameroon (see below).

Countries of natural occurrence not represented by known-provenance stands in the NT are Cameroon, Gambia, Guinea, Guinea-Bissau, Mali, Mauritania, Niger and Sierra Leone. However, it appears from Arnold et al. 2004, that several of these countries, eg. Cameroon, Mauritania, Niger and Sierra Leone, may have only minor occurrences of *K. senegalensis*.

It is desirable to broaden the genetic base by infusion of germplasm from those countries not yet represented by germplasm in Australia, and even from some of those relatively well represented already. This would allow the possibility of introducing superior provenances, and provide greater opportunities to increase the diversity of genotypes available for local selection for adaptability, pest tolerance, improved yield and quality, and for supplementation of the first breeding population. Availability of extra diversity could be especially desirable if predictions of climate change are borne out.

It is perhaps fortunate for the program that a considerable number of Senegal selects (36) from 4 provenances has been included in the first breeding population – because provenances from Senegal, which borders the sea in the west, might be adapted to the near-maritime environments that seem likely targets for the first extensive plantings in Queensland at least (Jago 2004, pers comms. G. Hooker 2004 and M. Bell 2004). Also fortunate is that the initial breeding population has such relative breadth (24 provenances from 12 countries plus unknown), although the actual levels of diversity and co-ancestry within it need to be determined.

## **Reproductive biology of *K. senegalensis* in northern Australia**

A good knowledge of the reproductive biology of the subject species is of fundamental importance in a conservation and tree improvement program (Sedgeley and Griffin 1989). General aspects of this phenomenon for *Khaya senegalensis* are given in Anon. 2004; but more detailed information is required in order to conserve and domesticate this species.

Observations made in the NT by the authors and in east-central Queensland by others (Bristow and Skelton 2004) indicate that seedling-propagated trees can flower periodically from around 10 to 12 years after planting. This means that the 'generation interval' for the species in an efficient breeding program could be 12 to 14 years or slightly more. [The generation interval in a tree breeding program can be defined as the time elapsing between the date of sowing seeds of trees of generation 'n', and the date when seeds from progeny of generation-n trees can be sown (giving plants of generation 'n + 1'). In order to optimise genetic gain on a per year basis, it is desirable to have the generation interval and optimal tree selection age approximately coinciding, or the former lower than the latter].

The species is monoecious with trees bearing numerous bisexual flowers in extensive panicles. Control of pollination (not necessarily required in a conservation and genetic improvement program) might be difficult because the small florets within a panicle appear to mature at different times, and isolation and emasculation are likely to be expensive. The species is presumed to be predominantly outcrossing, as seems to be the case in *Swietenia* and many other tropical tree species (Mayhew and Newton 1998).

The intensity of flowering varies among years (2004 was a year of very heavy flowering in the Darwin region). Tree crowns appear to require abundant space in order to flower heavily and mature large crops of pods. For example, in the stands near Gunn Point and Howard Springs, virtually no interior trees have done so, evidenced by the authors' observations of the crowns when attempting to collect seedpods, and the relative paucity (absence sometimes) of natural regeneration within stands. Also, it is predominantly the exposed portions of the crowns of edge trees that flower. Another characteristic of the species is that usually only a small to moderate proportion of open-grown or edge trees of appropriate age (these are the most likely to flower) will flower in any one year. As well, flowering may take place at quite different times among trees in the one area. Some trees may flower twice in the one year. The characteristic flowering time is in the latter part of the dry season, ie September to November. Seedpods usually mature a year later.

Grafting gives high rates of success. For example, all 142 trees selected in the conservation and tree improvement program in the NT have been propagated successfully with high success rates for almost all trees (average grafting success of more than 85%). At Weipa in Queensland, a success rate of around 90% was achieved in attempting approximately 150 grafts in 2004 (Bragg et al. 2004). Just less than 10% of 98 clones of grafted trees in the NT flowered at 2.5 years from planting, but heavy, general flowering might not occur until grafts are 5.5 years or more old from planting.

The rootability of cuttings from young seedlings is high (more than 80% across several settings totalling some 2 300 cuttings in work done at the Berrimah Research Station by the junior authors). It is considered this result can be improved based on the experience gained.

High rootability has also followed the setting of cuttings from grafts of 30 + years-old trees present in the conservation clone bank (described below). However, it is not known whether the rooted cuttings obtained from this mature material will show physiological ageing effects.

### **Potential options for conservation and genetic improvement of *K. senegalensis***

The development of an appropriate strategy for the conservation and improvement of *K. senegalensis* in the NT had to take account of the biology and the genetic resources of the species, as well as other resources available to the program, all in relation to achievement of the goals efficiently. Eight options, not mutually exclusive, were identified and considered:

- 1) Establish new provenance tests with a comprehensive array of provenances in parallel with planting selection blocks, as a base for future selection and breeding.
- 2) Establish provenance seedling seed orchards (PSSOs, *sensu* Nanson 1972) and/or clone tests using imported seed.
- 3) Undertake mass selection.
- 4) Create seed production areas (SPAs).
- 5) Establish PSSOs using local seed.
- 6) Undertake clone testing using hedged seedlings and/or coppice from selected trees.
- 7) Establish clonal seed orchards (CSOs).
- 8) Establish a gene recombination orchard (GRO, *sensu* Vanclay 1986) in association with progeny testing to begin a recurrent selection program.

A brief description and an outline of the pros and cons of each of these options, with respect to the situation in the NT, are given in Appendix 1. An outline of the approach adopted, which makes immediate use of the best and diverse, old, adapted trees in the c. 7 ha of stands in the Darwin region, is given next below.

## **Initial strategy adopted in the Northern Territory**

### **Approach adopted:**

The strategy adopted has two-overlapping phases:

- 1) a simple, first phase aimed at delivering somewhat-improved planting stock as quickly as possible, linked to
- 2) a long-term phase to involve recurrent selection in large, improving and diverse base populations in a manner similar to that of the program adopted so successfully with *Eucalyptus grandis* in Florida (Eldridge et al. 1994, pp 218-219), except that much of the seed for new base populations would be generated in a local, clonal GRO. As in the Florida program, there would be, if possible, infusions of seed from natural provenances (especially those identified above as being absent or little- represented in existing, local stands), and possibly from other improvement programs.

Flow charts depicting the facilities and activities involved in establishing and implementing the strategy, along with anticipated timelines, are presented in Figures 1 and 2. More details of proposed sources of improved material and anticipated delivery times are given in Table 3.

The components of the program outlined in Figures 1 and 2 are described briefly below.

- a) Phenotypic selection of at least a few superior trees from each of the 24 provenances (from 11 countries of nativity, one secondary plus unknown) represented in the mainland and Melville Is. stands. Selection criteria were to be high relative growth, good stem straightness, large bole length and good branching.
- b) Establishment of grafted clones of these trees in both a GRO, and in a conservation clone bank (CCB) for security, to ensure protection and use of the best of the provenance diversity present.
- c) Establishment of a series of hedge gardens comprising putatively superior seedlings and clones as available at the commencement of each.
- d) Establishment of successive series of clone tests for identification of deployment clones.
- e) Proposed establishment of CSO with collaborators using the seemingly-best 20, selected trees available in all to enable seedling- and/or seed-deployment options.
- f) Planting a second-cycle, base population as open-pollinated, GRO and CCB families (seed procured after a heavy, general flowering) and infusions, to enable future selection of superior, second-generation trees for on-going improvement.
- g) Culling of the GRO after (f).

Following seed collection (component f), GRO and CCB seed could be released for other purposes; that available after planned culling (see below), especially, could be used to advantage in extensive plantings, if there were a demand.

### **Breeding objective and selection criteria:**

The likely long-term breeding objective will be to achieve the highest, sustainable rate of production per ha of logs of highest value in terms of market demand. At present, when almost nothing is known of the genetic variation, heritabilities, correlations and relative economic values of traits affecting the breeding objective, selection of trees for the initial breeding population has been based on a)

experience that individual-tree relative growth, stem quality, bole length and branching are often heritable and strongly influence quantity and quality of stand production; and b) conservation needs.

It is considered that stem straightness and bole length should be the primary selection criteria, along with health, diameter, height and windfirmness, in the initial development of improved planting stock. This followed recognition of:

- a) the inferior stem straightness and bole length of *K. senegalensis* relative to several other species in the base population material of the 1979s, and in the multi-site taxa trials of the late 1990s reported by Reilly et al. 2004;
- b) the common success attending initial, intensive, phenotypic selection for straightness at least (Zobel et al. 1987); and
- c) the obviously large impacts of these two traits on recoverable volume of sawn wood.

Because we discovered limited occurrences of shoot borer *Hypsipyla robusta* on several grafts in the CCB (Darwin region), subsequently in the GRO at Howard Springs and in *Chuckrasia* at Berry Springs, in 2004, it will be essential to monitor plantings, even though it is known that *K. senegalensis* is less susceptible than several other species of Meliaceae (Griffiths et al. 2004; de Silva et al., 2004). This lesser susceptibility may be due in part to the fact that the shoot borer to which *K. senegalensis* is so susceptible in Africa (Anon. 2004) is a different species (Griffiths et al. 2004). The potential threat posed by *H. robusta* is another reason for planning to enhance the diversity of *K. senegalensis* germplasm available to the program by infusing additional accessions.

#### **Genetic gains anticipated:**

The likely genetic gains obtainable from the first phase of the program, which uses a well-tried and practical approach, cannot be predicted because no estimates are available of the population genetic parameters of the base population.

With the old, base stands available to the program in the NT of limited area and of relatively low uniformity of stocking and physical environment within them, the intensity and accuracy of the phenotypic selection is likely to have been low. Therefore, it is important to initiate clone and progeny testing of selections as soon as possible, to enable more effective selection of genetically superior trees with minimal delay. The strategy adopted addresses this imperative.

The first series of clone tests (likely to comprise more than 500 clones) should realise positive gains in stem straightness, bole length and growth from a combination of:

- a) the mild phenotypic selection of the parents of the open-pollinated progeny planted in the hedge garden (see below);
- b) mild, relatively accurate selection among the families in the clone tests; and
- c) relatively strong and accurate selection among clones within family.

Extra gains in the above traits should be obtainable in the second series of clone tests (Figure 2) because the clones will derive from seed produced from natural crossings of the seemingly-best first-generation clones in relative isolation in a special section of the CCB; and the numbers of families (including collaborators') and clones will be larger, allowing more intensive selection.

Likewise, selection of trees in the planned second-generation base population (replicated progeny tests on multiple sites with large numbers of trees from GRO and CCB seed mainly grown under relatively uniform conditions) should be more accurate. Subsequently, this should lead to the development of clones of greater genetic merit in advanced series of clone tests.

## **Program achievements via implementation of the strategy**

Achievements of the program since 2001, include:

- 1) Documentation of short- and long-term strategic plans in 2003 (Figures 1 and 2);
- 2) Phenotypic selection for relative growth, stem straightness, bole length and branching in each of 24 provenances (from 11 countries of nativity between Senegal and Uganda, and one secondary) and unknown sources represented in NT stands (1970s plantings, some 7 ha, all of which are threatened) in 2001 to 2003;
- 3) Establishment of 142 grafted clones in both the GRO (1.15 ha, 380 grafts) and the CCB (0.56 ha, 250 grafts) during 2002 (mostly) and 2004 to generate progeny with great diversity for future local selection, and ensure protection of the germplasm;
- 4) Establishment in 2004 of a first hedge garden with open-pollinated seedlings from 11 selected trees of the breeding population, rooted cuttings from the stumps of an additional 12 such trees and seedlings from a collaborator's select trees (total of 540 genotypes), for the development of rooted cuttings clones for planned field tests with first plantings in 2004-05 at sites already chosen;
- 5) Rooting (more than 80% success) of more than 2 000 cuttings from the hedge garden in 2004;
- 6) Congregation in 2004 of grafts of the seemingly-best 14/142 clones at one end of the CCB to promote production of seed from them to raise plants for a future, second series of clone tests;
- 7) Selection in 2004 of a site for a proposed CSO needed to facilitate a future option of using seed or seedlings for establishing plantings.

Limited flowering occurred in the CCB and GRO in 2004. Planting a second-cycle, base population as open-pollinated, GRO and CCB families and infusions, to enable future selection of second-generation trees for on-going improvement, will follow procurement of seed after the first general flowering expected in about 2006.

## **Research and other inputs needed to ensure development of the program**

The main aspects of the future direction of the program have been mentioned above or depicted in Figures 1 and 2 and Table 3, the latter outlining the means by which incremental genetic improvement of planting stock is to be achieved through to 2022 at least.

Imperatives critical to the success of the program will include:

- a) Ensuring adequate funding is provided for ongoing support of the work;
- b) Ensuring the protection and rapid development of the GRO and CCB so that seed then seedlings will be available with minimal delays for: 'fuelling' the series of clone tests, regenerating diversity for future cycles of selection (especially for stem straightness and bole length), and providing seed to planting programs;
- c) Enhancing genetic diversity by infusing new germplasm from natural stands, especially those in regions poorly or not at all represented in Australia eg. CAR, Cameroon; and
- d) Eliminating or minimising the threat of shoot borer.

The following appear to be the more urgent research needs:

- a) Estimating G x E interaction at the clone level across many sites;
- b) Documenting the periods of flowering of the clones in the CCB and GRO;
- c) Improving protocols for rooting cuttings of hedged seedlings and, especially, phenotypically-superior trees available in young stands (firstly for clone tests, and later for mass production of superior clones held in hedge gardens);
- d) Checking that rooted cuttings are not inferior to seedlings after, say, 10 years;

- e) Undertaking molecular studies of diversity, coancestry and levels of inbreeding in the several, current working populations: the first-cycle breeding population of 142 selected trees, the 2 000 trees in the trials described by Reilly et al. 2004, the first hedge garden, progeny of the CCB and GRO, the Queensland stands at Weipa and of the trials in the Bowen to Townsville region described by Dickinson et al. 2004, and seedlots recently introduced by various stakeholders;
- f) Investigate provenance and other genetic variation including genetic parameters; and
- g) Finding means for reducing the generation interval to less than the 12-14 years currently anticipated, perhaps optimistically.

## Conclusions

A good start has been made on conservation and genetic improvement of *K. senegalensis* in the NT. Prospects seem good for its success, provided the work undertaken so far is continued and expanded as is indicated here to be necessary, including the support of new research and development that is outlined in the section above. It is also desirable to continue the collaboration with Queensland groups, and to enlist collaborators from the Commonwealth and private sectors, in order to maximise the pool of resources of all kinds that can be utilised in the current beginnings of domestication of this promising species.

We believe the likely most efficient means for addressing the imperatives and research needs identified here, and a recommendation from Dickinson et al. 2004, would be the establishment of a cooperative genetic improvement program with *K. senegalensis* across northern Australia, as advocated in Nikles 2004. (The Dickinson et al. 2004 recommendation, based on their work in east-central Queensland, was “that the genetic improvement of this species is a high priority for plantation development in the dry tropics region”).

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Table 1. A summary of provenance trials established near Darwin and on Melville Island.

Location	Year of planting and no. provenances per location and year			Total no. of different provenances <sup>1</sup>
	1971	1972	1973	
Near Gunn Point, NE of Darwin	11	12	4	20
Tuyu, Melville Island	13	15	5	24

<sup>1</sup> Across all the plantings there are 24 different provenances.

Table 2. Inventory of selected trees of *Khaya senegalensis* propagated as grafts in both a conservation clone bank (CCB) and a gene recombination orchard (GRO) in the Northern Territory by country of original provenance (11 plus unknown) and number of provenances represented. (Additional trees may be selected in the future).

Country of primary origin of seed parents <sup>1</sup>	No. of provenances <sup>2</sup>	Nos. of trees selected for propagation in CCB, GRO	Average no. of trees selected per provenance <sup>3</sup>
Benin (previously Dahomey)	1	2	2
Burkina Faso (Upper Volta)	2	14	7
Central African Republic (CAR) <sup>4</sup>	1	6	6
Chad	1	3	3
Ghana	1	10	10
Ivory Coast	1	5	5
Nigeria	2	11	5-6
Senegal	4	36	9
Sudan	2	11	5-6
Togo	1	6	6
Uganda	4	17	4
Unknown via New Caledonia	3	13	4
Unknown via N Territory, Australia	One or more of the above	8	5
<b>TOTALS</b>	<b>24</b>	<b>142</b>	<b>6 (approx.)</b>

<sup>1</sup> Countries of nativity of *K. senegalensis* not represented in plantings in the N T of the 1960s and 1970s are: Cameroon, Gambia, Guinea, Guinea Bissau, Mali, Mauritania and Niger.

<sup>2</sup> There were 2 additional Ugandan provenances in the 1970/71 planting on Melville Is., but no trees were selected for propagation in the plots of these provenances.

<sup>3</sup> It is possible that, within provenances, some of the selected trees may be related (sharing one or more parents). However, crossing expected between provenances in the GRO and CCB will result in outcrossed rather than undesirable, inbred progeny.

<sup>4</sup> In view of the extensive distribution of the species in the CAR, infusions from the CAR are desirable.

Table 3. Anticipated times (possibly conservative) of the availability of increasingly-genetically-improved seed breeds and clones of *K. senegalensis* in the Northern Territory.<sup>1</sup>

Approx. year	Sources of seed breeds	Sources of clones	Remarks
<b>Present</b>	Some edge trees of stands planted in the early 1970s Street and park trees Imported seed	Not available	Only a modest proportion of trees bear pods, often precluding intensive parental selection and risking some inbreeding
<b>2005 onward</b>	As above	First hedge garden (HG1) planted in 2004	Untested clones – from cuttings ex HG1
<b>2008 onward</b>	GRO and CCB <sup>2</sup>	As above	The GRO and the CCB (unculled) may have small, useable pod crops from 2007 <sup>3</sup>
<b>2009 onward</b>	As next above	Second hedge garden (HG2) planted 2008?	Untested clones – from cuttings ex HG2
<b>2012 onward</b>	As next above	First hedge garden	Partially-tested clones selected in tests 5 yr old
<b>2016 onward</b>	As next above	Second hedge garden	Partially-tested clones
<b>2017 onward</b>	As next above	First hedge garden	Tested clones selected in tests 10 yr old
<b>2018 onward</b>	As next above, but of higher breeding value	Hedge gardens	Seed from culled GRO and CCB <sup>4</sup>
<b>2022 onward</b>	As next above	Second hedge garden	Tested clones selected in tests 10 yr old

<sup>1</sup> **Assumptions:** cuttings are available in quantity from hedge gardens one year after their planting, and of selected clones one year after test results become available; clone tests are assessed at ages 5 years (allowing clone selection on 'partial testing') and lastly at 10 years; a heavy, general flowering occurs in the GRO and CCB in 2007, 5 years after planting; progeny tests are assessed at age 9 yr and the information used to cull the GRO and CCB. See footnote (4) also. To enable a seedling-deployment option, it is also proposed to establish a clonal seed orchard of the seemingly-best clones in 2006; its impact is not elaborated here as no action has been taken on orchard establishment pending discussions with likely collaborators.

<sup>2</sup> GRO – gene recombination orchard; CCB – clone conservation bank (described in the text).

<sup>3</sup> Most grafts in the GRO and CCB are of 98 clones planted in early 2002. Older grafts of just less than 10% of clones flowered in 2004. However, a heavy, general flowering, that is needed before commercially-useable seed, ie. seed with a likely low level of inbreeding, can be collected confidently, is not expected until 2006 or 2007. Mature seedpods are available one year later.

<sup>4</sup> Progeny tests *cum* second base population from clones in the GRO and CCB may be planted in 2008, assessed in 2017 and information used to cull the GRO before flowering in 2017.

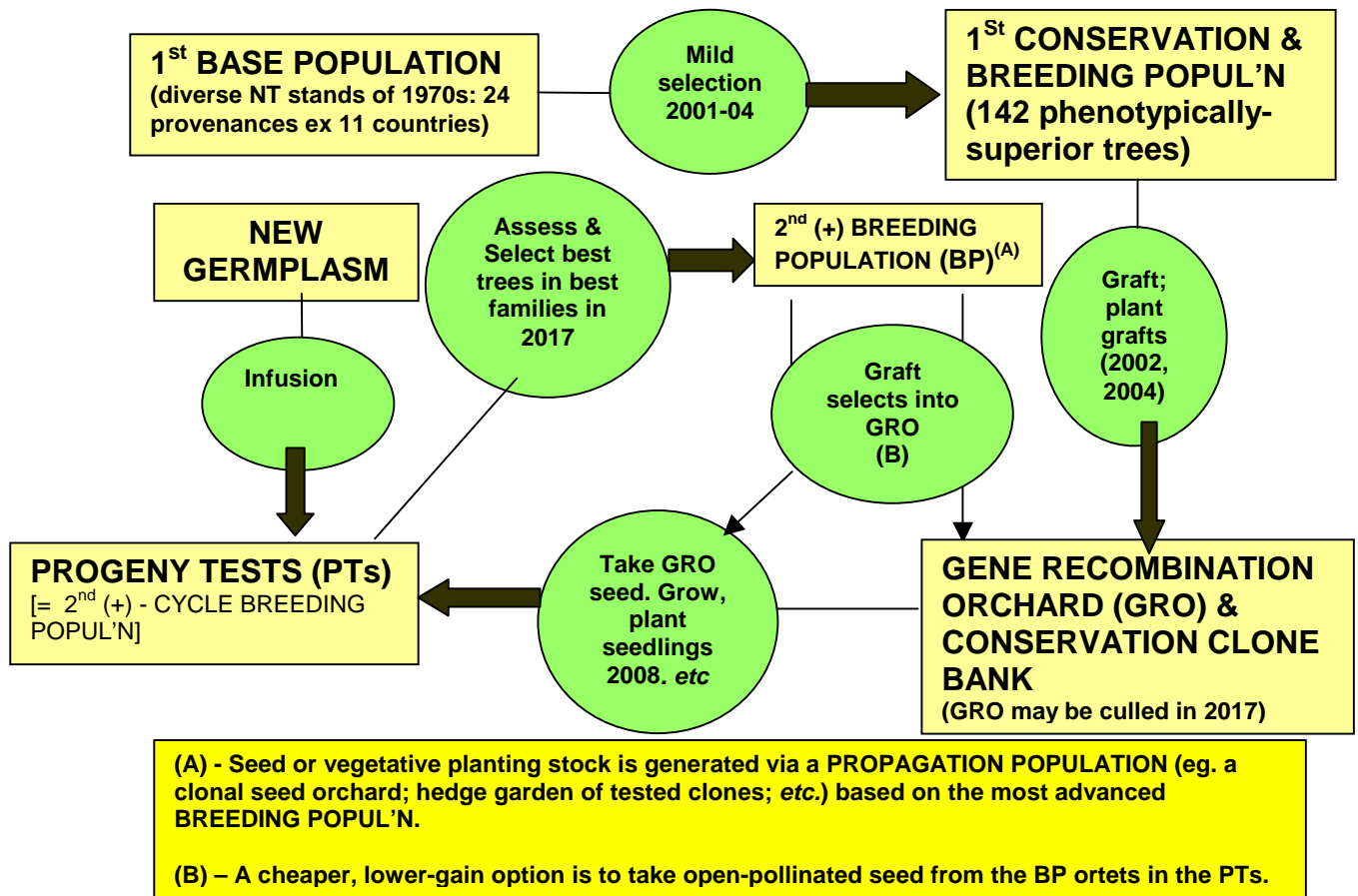


Figure 1. Flow chart depicting the long-term strategy for the conservation and genetic improvement of *K. senegalensis* in the Northern Territory (NT) via recurrent selection and mating of successive breeding populations, combined with periodic infusion of new material. See Table 3 for details of anticipated times of delivery of improved material.

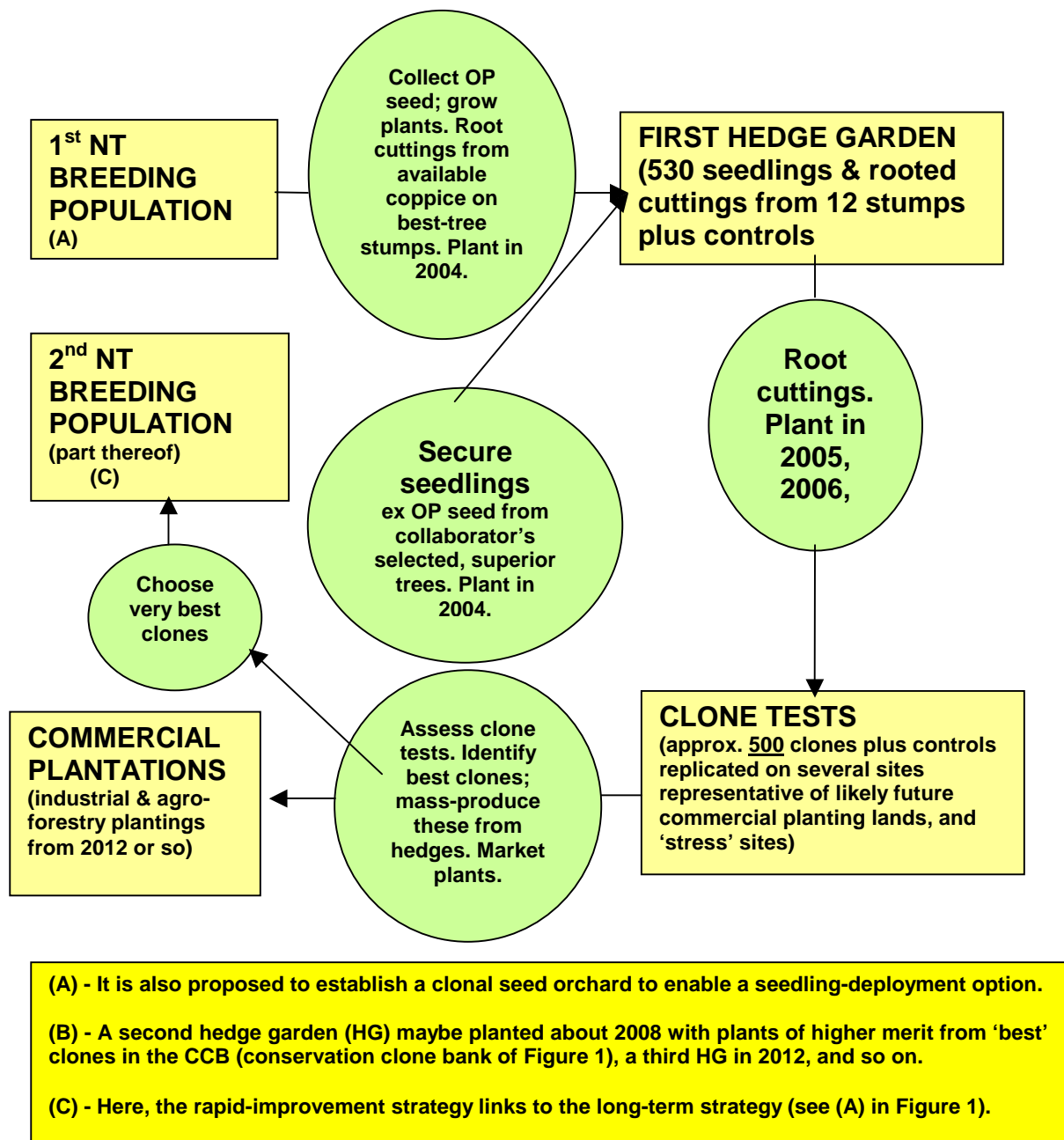


Figure 2. Flow chart depicting the first cycle of the strategy for the first-stage, rapid development of somewhat-improved planting stock of *K. senegalensis* in the Northern Territory (NT). See Table 3 for more details of anticipated times of delivery of improved material.

## Appendix 1

(NB References cited are detailed under **References** in the main text.)

Description and pros and cons of different options considered for the conservation and genetic improvement of *K. senegalensis* in the Northern Territory <sup>1</sup>

1. Establish new provenance tests with a comprehensive array of provenances in parallel with planting selection blocks. This approach would seem essential in view of the lack of knowledge of provenance variation, but it does not satisfy a perceived need for the delivery of somewhat-improved planting stock in a short time. Moreover, it would likely be a very expensive exercise to secure the required seed. It was recognised, however, that commencement of such work would be desirable with respect to a long term strategy, as demonstrated in the main text.

2. Establish provenance seedling seed orchards (PSSOs) and/or clone tests using imported seed. PSSOs comprise progeny from bulked or individual-tree seed collections from many trees of many provenances (Nanson 1972). This approach may be appropriate when knowledge of provenance variation is lacking and effective culling of inferior trees can be undertaken as the orchard ages, thus automatically retaining the best trees of the best families and provenances. However, in the present case, such an approach would have the same limitations as the previous option.

3. Mass selection. This involves selection of superior trees and collecting and using their seed for plantation establishment. However, very few of the selected trees in the NT produce seed. For example, in a sample of 38 trees selected in 2003 and felled for a wood study, only 10 provided seed, and that in quite limited amounts in some cases. Moreover, gain from mass selection at the low intensity that could be adopted would realise very limited genetic gain (Shelbourne 1992).

4. Create seed production areas (SPAs). The only potentially-suitable stands of seed-bearing age available in the NT are the provenance trials near Gunn Point and some stands at Howard Springs. These stands have not been thinned and, as expected, crown development of interior trees is very limited with only rare trees producing seeds. These are unlikely to respond to thinning for SPA development.

5. Establish PSSOs using local seed. It has been mentioned already that very few of the trees selected in the NT produce seed, so it is not possible to secure the material required for a PSSO based on local seed. Furthermore, it would be some 15 years before such a PSSO would produce seed.

6. Undertake clone testing using hedged seedlings and/or coppice from selected trees. One or other of these two approaches has been highly successful with many trees species when certain conditions apply (Evans and Turnbull 2004; Leakey, 2004). One potential source of superior trees for coppicing is the some 2 000 saplings in the trials planted in the NT in 1998-99 and 1999-00 (Reilly et al. 2004). However, a search of nearly 2 000 trees in these plantings yielded only 5 candidate trees on the joint bases of relative growth, stem straightness, bole length and branching. It is planned to attempt to coppice and root cuttings from these trees.

The *K. senegalensis* stock in these young trials traces predominantly or wholly to wildlings gathered from the edge of a stand at Howard Springs planted in the 1970s with stock of a Senegal provenance, D417 (Reilly et al. 2004). A small proportion of edge trees, only, produced seed and wildlings. Therefore, its genetic base is likely to be rather narrow and possibly inbred.

The approach of clone testing from hedged seedlings from open-pollinated seed of selected trees was an option that has been included in the program (Figure 2). Some details are given under **Achievements** in the main text.

7. Establish clonal seed orchards (CSOs). This approach has merit because only about 20 select trees could suffice, they could be the very best phenotypes available and, potentially, the genetic gain could be larger than that obtainable by any of the other means outlined above, with the exception of clone testing from suitable material (Shelbourne 1992). Moreover, orchard seed could be expected to be available within just several years of the planting of the grafts, because mature scions would be used. The strategy actually adopted (see main text) includes a proposal to establish a CSO.

8. Establish a gene recombination orchard (GRO) in association with progeny testing.

This approach is to initiate a program using the opportunity to select adapted trees of good development within the existing stands (some 7 ha) of rotation-age present near Gunn Point, Howard Springs and on Melville Is. These stands represent 25 provenances from 11 countries spanning the west to east range of the species (from Senegal – 4 provenances to Sudan and Uganda – 6 provenances). It is considered that, provided grafted clones of these trees, selected in the wide range of natural-stand conditions they represent, flower with considerable overlap in the GRO in the Northern Territory, then the orchard would be expected to generate much genetic variability which could be subjected to local selection in a number of environments targeted for future plantings in northern Australia. Moreover, crossing between provenances would produce progeny with no inbreeding. The progeny generated could be supplemented, if possible, by future accessions of new germplasm, hopefully from regions in west Africa not represented in the GRO.

Risks of this approach include the possibility that flowering of the grafts of trees selected from such a wide range of provenances may not be well synchronised resulting in a limited amount of inter-crossing. As well, crossing that does occur among the clones of such disparate provenances might disrupt co-adapted gene complexes resulting in many maladapted progeny.

Regarding the latter point, counter arguments could include the following:

- a) It is likely there would be considerable crossing within and among similar provenances.
- b) Seed orchards of many tree breeding programs include families or clones of different provenances (examples in *Eucalyptus* are mentioned in Eldridge et al. 1994);
- c) Even inter-specific crossing within *Eucalyptus*, *Pinus* and other species has given outstanding recombinants that have been used very successfully in extensive and long-running plantation programs via clonal or family forestry (Potts and Dungey 2004), and this is so to the second generation among some interspecific *Pinus* hybrids (Nikles et al. 1999); and
- d) Many intact coadapted gene complexes of adaptive value in the natural habitats might not be of importance in new environments where the species is grown as an exotic; perhaps the reverse.