Plantation improvement using clonal propagation - an overview of the latest technology in Australia

Peter and Ann Radke
Clonal Solutions Australia Pty Ltd

With an appendix on
Variation in tree species, and improvement and propagation options – an explanation

By D. Garth Nikles

Abstract

Key words: eucalypt, hardwood, plantation, clone, seedling, cutting propagation.

This paper discusses the current status of the hardwood plantation industry in Australia with regard to seedlings and clones. It explores the advantages of clonal forestry compared to traditional seedling plantations, the factors that affect the commercial viability of clonal propagation and clonal forestry. The latest technology available at Clonal Solutions Australia Pty Ltd is described, and the need for partnerships between breeders, timber companies and clonal nurseries is advocated.

Introduction

The paper comprises two parts. In the first part, the relative merits of clones (as rooted cuttings) versus seedlings are discussed. In the second part, our experiences, as proprietors of Yuruga Nursery are given.

Clonal Solutions Australia (CSA), a spin-off company of Yuruga Nursery, is currently the only nursery in Australia mass-producing clones of eucalypts in large-scale commercial quantities for the forestry industry, and as such is at the ‘cutting edge’ of the forest nursery industry.

The comments and opinions expressed in this paper are based on our extensive personal experience, and on information and ideas by way of personal communications with our many customers and contacts within the forestry industry throughout Australia.

Variation in tree species, and improvement options

Cloning is a propagation technology that can be very effective in making practical use, via ‘clonal forestry’, of proven superior individuals occurring in nature or developed by breeding.

The alternative (traditional) propagation route to improved plantations, ‘seedling forestry’, involves mass selection for various kinds of seed orchards that in turn provide improved seed. Although this approach has often served well in the past, and will continue to do so in appropriate circumstances (usually where requisite resources for clonal forestry are lacking, or profitability of it would be marginal), clonal forestry is currently showing great potential in the forestry industry.

Leakey 2004 outlines the conditions under which clonal forestry is an appropriate option and, as background to enable a better understanding of clonal propagation, a simplified explanation of variation in tree species and improvement options has been provided as an appendix, kindly written by Garth Nikles.

Clonal Propagation

What is a clone?

In simple terms, a clone comprises identical copies of an individual. That is to say, the members of a clone have the same genetic constitution except insofar as mutation has occurred during propagation (Abercrombie et al. 1960). In forestry and horticulture, a clone comprises all the descendants of a single plant, produced by vegetative propagation.

A clonal forestry plantation, produced from the same parent material, consists of trees that are all expected to be genetically identical to each other. Traditional seedling plantations however consist of trees that are similar to each other but each individual tree is different to every other tree owing to, in the majority of cases, the combinations of their parents (male and female) being different. Seedling plantations (where there has been no special selection or breeding of the parents) can contain vigorous plants and runts, fast growers and slower growers, tall straight trees and short crooked ones. Further explanation is given in Appendix 1.

Care, however is still needed when propagating clonal material from different parts of the same parent plant as they may have different properties, depending for instance whether the shoots are orthotropic (vertically growing) or plagiotropic (non-vertical to horizontally growing) or from the root.

Plantation Improvement

In a nutshell, relative uniformity is a feature of clonal plantations whereas variation to a greater or lesser degree is a feature of seedling plantations.

The extent of the variation in seedling plantations can be reduced by using genetically-improved and graded seed, rigorous culling prior to planting, and by silvicultural thinning in the field.

The clonal approach to plantation improvement is to identify a small number of individual trees, by replicated tests in target environments conducted over several years, that are superior in a desired combination of such traits as tree form, wood quality, speed of growth, tolerance of salinity, etc., and to reproduce them vegetatively, to create a plantation of trees all identical to these superior individuals.

In the plant world there are a number of ways of producing clones, including layering, marcotting, grafting, tissue culture and cutting propagation. Of all these, the method at present most suited to mass producing clones for timber plantations at a commercially viable price is **cutting propagation (**i.e. production of rooted cuttings) and this is the method used at Clonal Solutions Australia.

Clonal forestry plays a significant role in many forestry plantation operations around the world, and is now common practice in some softwood pine plantations in Australia. The Australian hardwood industry is a notable exception. We believe that CSA can now provide the technology to enable the Australian hardwood industry to catch up with much of the rest of the world.

Why do many timber companies around the world plant clonal plantations?

Well-executed clonal plantations confer many advantages over traditional seedling plantations.

Clonal plantations are based on superior individuals that have been selected by the plant breeder for their superior genetic qualities.

Qualities selected by breeders for the mass-production of elite clones may include:

- Increased **growth rate**
- Superior **vigour**
- Superior **form/shape** (eg apical dominance for sawn log production)
- Increased timber **volume/yield**
- Superior **timber qualities** (eg strength, durability, density, paper quality)
- **Pest and disease** resistance
- **Drought** resistance
- Suitability to specific **soil types**
- Suitability to specific **climatic zones**
- **Salt** tolerance

The tree breeder usually selects for a limited number of the most important traits as little progress can be made if selection is attempted for a large number of traits.

As well as genetic advantages, clonal plantations offer **additional flow-on benefits** such as:

- **Relative uniformity**
- Low levels of **runts and deaths**
- Lower initial **stocking rates**
- Lower **establishment costs**
- Cheaper **harvesting costs**
- Increased **profitability**

Elite clones supplied to plantations by nurseries such as CSA are uniform for two reasons:

- The rooted cuttings that each comprises, are identical genetically; and
- In the case of CSA, the production process used incorporates extensive sorting for age, development, height, vigour etc of the individual plants produced.

This uniformity results in the following advantages to the plantation owner:

- All plants supplied are of **plantable quality** and the planting team does not need to sort, select or discard, thus resulting in more **efficient planting** and **cost savings during the planting process**;
- 100% of the plants delivered are virtually identical in size, vigour and growth characteristics including growth rate. This means that there are **few runts or deaths** in the plantation, and therefore **no re-planting** (as a result of poor genetic performance) is usually necessary, resulting in considerable **cost savings** at the planting stage.
- Barring a low natural mortality, all plants grow into good quality trees in the plantation. There is little or **no need for thinning of runts** as the plantation grows.
- It is generally considered that clonal plantations do not require the same degree of early thinning, and so they are usually **planted at a lower rate per hectare than seedling plantations.**[1]
- Since growth of all trees across the plantation is uniform, except due to differences in local sites, **harvest** operations are **easier**, more **efficient** and more **cost effective**.
- All plants in a clonal plantation have been selected for **superior qualities,** which in most cases result in **higher return** at harvest.

[1] For example, a typical seedling eucalypt plantation may be planted at 1000 stems/ha compared to a clonal plantation at the same site planted at 800 stems/ha. The lower stocking of clonal plantations may remove the need for the early thinning of poor quality trees. However, stocking densities at different plantation ages (maintained by appropriate thinning) will still need to be determined by requirements to maintain 'site capture' (to avoid invasion of unwanted growth), to meet particular log specifications and markets appropriate to the growth stage of the plantation, the end use of the timber and when a market may be available.

Replanting is to be avoided ‘at all costs’ as it is very expensive since it requires the purchase of replacement plants, and expenditure on additional, more costly, labour to replant replacements located usually at random all through the plantation. Usually there is less need for replanting in clonal plantations.

Price considerations

After superior clones have been identified within seedling-derived populations (which can be very expensive, especially if breeding is continued to develop even better clones), the only additional cost in establishing a clonal hardwood plantation compared to a seedling plantation is the higher cost of a clonally produced plant.

Clonal propagation is well-entrenched in the softwood industry in Australia, especially with *Pinus* hybrids in Queensland. The plant physiology of softwoods however is very different to that of hardwoods and clonal propagation of hardwoods, especially eucalypts, can be a totally different scenario and at the other extreme end of the spectrum regarding difficulty, technology and capitalisation. This impacts on price, and so at face value there is a perceived price barrier (by the grower) working against the establishment of hardwood clonal plantations, even though a closer study of the full economic picture may show otherwise.

However, cloning of many hardwoods has at least two advantages over most pines in that, firstly, ‘selection-age’ hardwoods can usually be coppiced successfully, and clone tests can begin with ‘selection age’ trees. In contrast, only extremely few pines can be coppiced successfully. Secondly, the severe problem of ‘ageing’ of hedged mother plants of pine can mostly be avoided in hardwoods, as ‘ageing’ mother plants can usually be replaced from fresh coppice from rejuvenated stumps, either of the original selections or hedges.

In general, the price of rooted cuttings of clones is about two to three times the price of mass produced seedlings, due to the high labour costs in the production process, the high level of technical skill required and the high level of capitalisation required by the nursery. Whereas a wholesale eucalypt seedling for southern plantations may cost, say, 30 cents, a *Eucalyptus grandis* x *E camaldulensis* rooted cutting of a selected clone will cost, say, 60 cents.

Depending on the total cost of seedlings relative to other establishment costs and the cost to a company of the developed and chosen clones, the additional cost of purchasing the plants (as rooted cuttings) for a clonal plantation may be quite small and may be offset many times over by the flow-on savings. Clonal plantations can therefore be a very cost-effective forestry operation, particularly for shorter rotation crops or where the use of clonal material significantly shortens the rotation.

It must be stressed that the above general cost comparison applies to southern plantations only. In north Queensland, as seedlings have traditionally been planted from ‘Forestry’ or ‘Native’ Tubes, that cost between 80 cents and $1 per plant wholesale depending on species and quantity, the cost difference of clonal planting stock may be minimal and the grower may save money immediately if the clonal material is of proven superior productivity and quality.

Quikpots™

The final impediment to clonal forestry in Australia has been, until recently, the dreaded ‘crack-pot’. For the clonal production process to be commercially viable, clones need to be propagated in individual containers so that each plant can be handled individually. Planters dislike the crack-pot because it has to be removed from the root-ball during planting, which slows down the planting process and increases planting costs. However, the perfect container did not exist in Australia, and the clear plastic ‘crack-pot’ has at least done the job.

Following a world-wide search for the ideal product, CSA believes it has now introduced the perfect solution, which we have called the **Quickpot™**. The Quickpot™ is a biodegradable paper pot that allows the plant to be planted directly into the ground without the removal of any container. It is a totally new product, and bears little if any resemblance to the Jiffy pot or other products that may have been tried in the past. The Quickpot™ also allows CSA far greater flexibility to alter the propagation medium according to specific requirements, and so we are now able to better adjust the media to suit conditions in the field at planting. We have found the Quickpot™ to be a great product, and we think it should lead to a boom in clonal forestry.

Why has the Australian hardwood plantation forestry industry not gone down the clonal route to date?

Until recently, the Australian hardwood industry has been largely based on the logging of native forests. Historically, there has been no significant hardwood plantation estate and therefore no pressure for plantation improvement.

It is only in the last 15-20 years, that changes in government policy, the phasing out of native forest harvesting on State lands, changes in tax laws, and the ‘Plantations for Australia: 2020 Vision’ have created a climate that is conducive to the establishment of a large scale plantation hardwood industry.

Although Australia has been a member of the International Convention for the Protection of New Varieties of Plants (UPOV) since 1989, has passed a Plant Variety Rights Act in 1987, a Plant Breeders Rights Act in 1994, and became a signatory to the most recent UPOV Act of 1991 (UPOV 1991) in January 2000, tree breeders have generally chosen not to take out protection for their products (for their own reasons), and most companies have been reluctant to invest heavily in this field. However Plant Breeders Rights legislation does provide a simple and cost-effective way for breeders to protect the ownership of their product, and many companies are now starting to focus on proprietary breeding and selection for plantation improvement.

There is now an increasing interest in clonal forestry, not just in the southern established blue gum plantations, but also in the emerging hardwood plantation industry in tropical Australia.

However, the main reasons for the continuing, predominant use of ‘seedling forestry’ with blue gum (*Eucalyptus globulus*) in southern Australia is the lack of conviction that clonal forestry is commercially viable, due to the generally low rooting percentage of the species and costs; and the fear that propagation of the rare ‘good rooters’ only, would involve great opportunity cost in terms of diversity likely to be lost in plantations and breeding programs (pers. comm., Garth Nikles 2004, based on participation in ‘Workshop on benchmarking clonal propagation for the blue gum plantation industry’, 7-12 March 2004, Mt Gambier, South Australia).

Clonal Solutions Australia (CSA)

About 10 years ago Yuruga Nursery predicted the need for clonal material for both the forestry and agricultural industries, and so building on extensive experience in the production of 10 million elite tea-tree (*Melaleuca* spp) clones, started doing clonal work with eucalypt hybrids. In the early stages, we were working with fairly small runs of only about 5,000 to 20,000 plants. In a ‘pilot stage’ such as this, strike rates were not critically important.

At this time it was widely accepted -in general horticultural circles in Australia -that eucalypts could not be propagated by cuttings, and so the success of Yuruga Nursery in this field captured widespread attention. Very soon we were receiving much larger orders and so suddenly strike rates, efficiency and productivity became very important if we were to maintain the commercial viability of our operation.

We looked overseas at the methods used in countries such as South America and South Africa, but we soon discovered that the economic and social climates in these countries dictated very different cost structures in their production processes, which had no application in Australia.

We quickly realised that, rather than copying a ‘recipe’ from overseas, we would have to go back to first principles and develop our own systems and processes that suited the particular economic and social climate under which we operate in Australia.

Important factors that impact on clonal production in Australia compared to overseas countries are: The high wages in Australia, our industrial relations system, our workplace health and safety laws, our environmental laws, and the costs of our goods and services. So the progression from pilot stage to full-scale commercial production presented many new and complex issues in not only the technical field but also in the management and personnel areas.

Because clonal production is very labour intensive it is very important to achieve a high strike rate since every plant thrown out costs money. This is actually the secret of our success since it forced us to examine and fine-tune every aspect of the production process.

Why has CSA succeeded where others haven’t?

In a nutshell, CSA has succeeded because it is a small private company able to respond quickly to changed conditions.

For a small company such as ours to conduct self-funded R&D, we have to get results as quickly as possible because of the imperatives of maintaining cash flow and income on a daily basis. To ‘crack the code’ for commercial mass clonal eucalypt propagation in a first-world country was not an easy task, and so we had to make major break-throughs very quickly, or give up the idea.

Where and what are our major markets?

To date, our major markets have been where the major hardwood plantation industry has been located, ie southern Australia including Tasmania, Victoria, New South Wales, South Australia and Western Australia, and in southern Queensland.

Our production to date has included 6 to 7 million rooted cuttings of clones of *Eucalyptus grandis x E camaldulensis* hybrids (Figure 1), as well as other eucalypt hybrids such as *E grandis x E globulus*, *E urophylla x grandis,* as well as pure *E saligna* and pure *E. camaldulensis*.

More recently, some of the major companies are venturing into tropical Australia, which opens up a range of different species such as *E. pellita*, *E. torelliana* (syn. *Corymbia torelliana*) x spotted gums crosses, *Acacia mangium*, *Tectona grandis* (teak), *Khaya* spp (African mahogany), etc.

Why is CSA located at Walkamin on the Atherton Tablelands?

We are often asked how we continue to operate so successfully when we are located so far from many of our major markets.

Freight

Firstly, there is a widespread misconception about the cost of freight. Freight in bulk quantities is not expensive. It costs only 1 or 2 cents to get a plant to southern Australia in full semi-trailer or B-double loads.

Climate

Secondly, the location is an important factor in the success of the product and the production systems, and we seriously doubt that a large-scale hardwood clonal production nursery could remain commercially viable in southern Australia.

- Clonal cutting production depends on the harvesting of mother-stock for the material used in the production process. In northern Australia, the climate allows for year round **regrowth** and **continual harvesting** of mother-stock, and hence **year-round production**, compared to only the summer months in southern Australia.

- The time between setting the cutting and the plant being ready to plant in the field is only about **10-12 weeks** in northern Australia, whereas in southern Australia this is typically about 20 weeks.

These two factors combine to allow for very large, year-round production runs in tropical Australia.

CSA’s site at Walkamin has the additional benefits of being outside the cyclone belt, it has no hail or frost, a very large number of sunny days (plants need sunshine to grow quickly), and relatively dry air leading to minimal fungal diseases. It’s a good site on the main highway and close to the regional centres of Mareeba and Atherton for reliable supply of goods, services and labour.

The location has definitely been a major contributor to our success.

Accreditation

The nursery industry in Australia has introduced an Accreditation Scheme[2] to identify those nurseries that operate to Industry Best Practice standards. Of the thousands of nurseries in Australia, only about 200 are accredited, including Yuruga Nursery and CSA.

Accredited nurseries are audited twice a year against a rigorous set of standards. The accreditation scheme is focused on plant quality, plant health (pests and diseases), and environmental issues. It is strongly customer focused, aimed at ensuring the customer gets the best possible quality plant.

A key focus is the minimisation and prevention of soil borne fungal diseases such as the root-rot disease *Phytophthora* which at the least lowers productivity and growth, and which has the potential to absolutely decimate a plantation. If you doubt the seriousness of this issue, ask an avocado grower. No experienced and long-term avocado grower would ever consider buying anywhere than from an accredited nursery.

The Accreditation Scheme is the public’s means of identifying superior nurseries and it has been set up for its protection.

The strongest possible advice we can give is: Don’t place your venture at risk by purchasing your plants from non-accredited nurseries.

[2] Nursery Industry Accreditation Scheme, Australia (NIASA), Best Management Practice Guidelines
Nursery and Garden Industry Australia, www.ngia.com.au

Partnerships

For a successful clonal plantation programme, it is essential that there is a close relationship between the breeder and the nursery, and between the timber company and the nursery.

The breeder and the nursery

An extreme, hypothetical example may serve to illustrate the point here. If a breeder spends years breeding his ‘perfect’ plant without testing its ‘propagability’ along the way, there is a chance that the perfect plant may turn out to be a poor propagator which is not commercially viable, and all the work may come to nothing. While it is possible -in general -to propagate any plant clonally, some plants are definitely easier than others.

In practice, the breeder of material for clonal forestry will be producing a considerable number of families from which candidate trees will be identified via tests; those candidates with the best combination of performance in relation to the breeding objective, combined with high ‘rootability’, are those most likely to be chosen for adoption in clonal forestry for that stage of the program.

It is important that the breeder has a close relationship with the nursery (and vice versa) from the start so that the nursery can run propagation trials at the same time as the breeder is running the breeding programme and field trials. In this way, decisions can be made along the way with a view to assessing the commercial viability of the outcomes at every stage.

CSA has extensive experience in this regard, having screened over 1000 different clones for ‘propagability’ and commercial viability, involving rigorous trial methodology and data collection and analysis in both nursery and long-term field trials.

We note with some concern that some breeders still conduct their own propagation trials. Breeders (in general) are trained as research scientists, not propagators, and where the propagation skills and/or facilities are less than optimum, there is a strong possibility that the outcomes of the propagation trials may be compromised by factors other than the inherent ‘rootability’ of the clone. Where possibly millions of dollars ‘ride’ on the outcomes of such trials, we would strongly suggest that the trials are conducted by experts in the field, such CSA.

The timber company and the nursery

Clonal propagation and traditional seedling propagation are very different processes with very different cost structures and pressures.

In very simplistic terms, seedlings can be regarded as a commodity product whereby an order is placed, the grower goes to the cold room (although bearing in mind that a stock of seed has to be maintained and seed collection can require planning), he/she takes out the bag of seed and sows it in basically one run. All skilled nursery supervisors are able to do this and a simple customer-supplier relationship is well suited to seedling production.

Clonal propagation, involves a totally different process.

Most importantly, a bank of live mother-stock plants must be maintained in a condition that will allow propagative material (eg cuttings) to be brought up to production quickly, whether they are in current production or not. Mother-stock maintenance is an expensive and continuing process. Once an order is placed the mother-stock must be quickly brought up to production mode, and then cuttings harvested, prepared and set on a daily and continuous basis. Each cutting is individually handled, and so cutting production is very labour intensive.

To be commercially viable, clonal propagation is therefore a continuous process with heavily weighted 'upfront' and mother-stock costs, expensive and specialised facilities, and high labour input. In addition, a skilled labour force needs to be retained even during periods of no production since training costs are very high, and the expensive facilities need to be in use all the time to justify the high capitalisation costs.

As a result of these pressures, clonal production runs best where there is a close relationship between the timber company and the nursery (and vice versa) so that efficiencies can be found in forward planning and continuous production, and this is reflected in the fact that most large clonal nurseries around the world are owned by timber companies.

Conclusion

Clonal forestry in Australia may be poised for enormous growth. In southern Australia, companies are moving out into more marginal land with lower rainfall, owing to reduced availability of suitable land, and this is where breeding and clonal propagation can supply many answers. Because of the shortage of land in southern areas, plantation companies are also moving their sights north to the sub-tropics and tropics. As tropical forest plantations develop, there is an opportunity for innovative companies to aim for higher yields through breeding and selection, and through vegetative propagation programmes for species that may lend themselves to clonal propagation. Clonal Solutions Australia looks forward to forming lasting and productive relationships with progressive companies in this regard as we move into a new era in the forestry industry.

Acknowledgements

The authors wish to thank Garth Nikles and Ian Bevege for their comments and suggestions in the completion of this paper.

References

Abercrombie et al. 1960. Dictionary of Biology. Penguin.

Commonwealth of Australia, Plant Variety Rights Act, 1987

Commonwealth of Australia, Plant Breeders Rights Act, 1994

International Convention for the Protection of New Varieties of Plants (UPOV) 1991 (1961 revised 1972, 1978, 1991).

Leakey, Roger R. B. 2004. Clonal approaches to hardwood forestry in the tropics. Working Paper in: Bevege, D.I., Bristow, M., Nikles, D.G. and Skelton, D. (eds). 'Prospects for high-value hardwood timber plantations in the 'dry' tropics of northern Australia'. Proc. of a Workshop held 19-21 October, 2004, Mareeba, Queensland. Published as a CD-ROM by Private Forestry North Queensland Association Inc., Kairi, Qld.

Figure 1. A shipment of 70,000 rooted cuttings of *Eucalyptus camaldulensis* x *E grandis* clones being loaded onto transport for delivery to NSW.

Appendix 1

Variation within tree species, and genetic improvement and propagation options

D. Garth Nikles

Department of Primary Industries and Fisheries, Horticulture and Forestry Science, Indooroopilly, Queensland, Australia, 4068 Garth.Nikles@dpi.qld.gov.au

This simplified explanation is provided as a general reference for readers, and has been compiled from texts and experience. Most of the terms associated with the topic are highlighted and could be further elucidated with the help of a text such as Eldridge et al. 1993. That text includes a glossary of tree breeding terms.

Suppose seed is collected from several trees in a natural stand of a single species at a particular place (P1) (**provenance** P1) and the seed is mixed together, seedlings are raised and then used to establish a plantation (which will be of provenance P1). Later, when a random section of the plantation is inspected carefully, especially before any removal of inferior trees by thinning, considerable variation between trees will be seen in such characteristics as height, diameter, stem straightness, bole length, perhaps health and other traits. This kind of variation that can be seen directly (or indirectly as in the case of wood density and other such 'hidden' traits) is called **phenotypic** variation. It results from the combined effect of the genetic make-up (**genotype**) and the local **environment** of each tree. This can be summarised in the statement: Phenotype = Genotype + Environment.

Only the portion of a tree's phenotype that is due to genetic effects (genotype) has a chance to be passed on to its offspring. Even when reproduction of a tree (the **ortet**) is via **asexual** propagation, i.e. **cloning** (which 'copies' the original genotype), all the copies (**ramets**) may not have exactly the same phenotype (nor as that of the ortet). This is because of **propagation ('c') effects** and the different environments that the ramets occupy in and across the places of planting. So, clones are not absolutely uniform, e.g. in appearance, though very close to it.

The variation of a trait such as tree height in a population can be estimated via statistical analyses of measurements taken in trials, such as **progeny trials** or **clone trials**, comprising replicated blocks containing randomly allocated offspring of parent trees. The total, i.e. **phenotypic variation**, can be apportioned to sources such as blocks (i.e. specific sites (blocks) in which the trees have been planted), parents or clones and other sources, and the **genetic variation** component can be estimated. The proportion of genetic to total variation of a trait that is transmitted to sexual offspring is the **heritability** of that trait. It can be calculated either as **individual-tree heritability** or **family heritability**, the latter always being the larger. These heritability ratios are always less than one because sexual reproduction involves **recombination** of genes. When propagation is via cloning, however, all of the genetic variation is expected to be passed on. In this case the heritability is called **broad-sense heritability** or **clonal repeatability** (Falconer 1989); its ratios will be larger for the same traits than those of individual-tree and family heritabilities, but still less than one.

If phenotypic superiority of a tree is due largely to favourable micro-environment, little of such superiority will be passed on to its offspring, via either sexual or asexual reproduction.

The relevance and importance of the heritability concept is its key role (along with **selection intensity**, which is related to the proportion of trees selected to be parents) in determining the **genetic gain** from different breeding and propagation options. One definition of this gain is the proportion of the **selection differential** (ie. the difference between the means of the trees screened and of the trees selected) that is exhibited by the progeny. This can be summarised in the statement: Gain = Selection differential x Heritability.

Remembering (from the above) that broad sense heritability, associated with cloned individuals (produced by asexual reproduction), is always greater than that under sexual reproduction of the same individuals, it is easy to see, from the above equation, why clonal propagation can produce more genetic gain. It captures a larger amount of the selection differential. As well from the above, the ramets of each clone are relatively much more uniform than seedlings from the same parent (with rare exceptions). It is also true that the genetic gain produced by breeding can be captured more rapidly via cloning than via seedling propagation. However, these benefits of cloning come at higher developmental and propagation costs, and only when the biology of a species permits.

The genetic part of the phenotypic variation among individual trees in a **full-sib family** (i.e. the progeny of one seed and one pollen parent) usually results from genetic **recombination**, or **mutation** or both occurring during sexual reproduction. Families from a single seed parent and two or more pollen parents (loosely called **half-sib** families) will have greater variability. A stand comprising such families of a species and similar of one or more species that can cross pollinate, or when pollen of cross-compatible species migrates to it, then **hybridisation** is a third possible source of genetic variation among offspring of trees in such a stand.

The commonest pollination mechanism is **cross-pollination,** via wind (e.g. pines) or insects, birds or animals (e.g. eucalypts - one or more of these **vectors**). **Self-pollination** is another**.** Natural (**open) pollination** often involves a degree of **neighbourhood inbreeding** because neighbouring trees can have one or both parents in common (as seed from mother trees may be 'showered' around the parents). This can lead to undesirable **inbreeding depression**

Most forest tree species are distributed in nature in stands, of varying sizes and stockings that are discontinuous over geographic ranges of varying extents encompassing different environments. If environments over the range of a particular species are substantially different, and especially if the species' distribution is broken into patches with discontinuities permitting little or no **gene exchange** between patches, then the **gene pool** of the species will tend to evolve in association with the climatic, edaphic and biotic factors encountered. This is because, under the influence of **natural selection**, offspring most fitted for survival and reproduction locally are the main progenitors of the next generation of trees there. This can result in **provenance variation** being detectable. Other influences on variation within a species can include the patterns of environmental gradients, climate change, changes in population sizes over time (especially occurrence of '**bottlenecks**', i.e. severe reductions in population sizes), other catastrophes, hybridisation and the breeding system alluded to above. Therefore, the patterns of species' variation, evolved in response to often interacting factors, may be quite complex and vary with traits, between different species and in time. While there is sometimes a good relationship between parameters of climate, for example, at provenance origins, and performance in survival or plant damage traits in plantings elsewhere, the predictability of growth in a new environment is generally low. (The success of many species as **exotics** shows their broad **adaptability**). Thus, intensive sampling of a species through its range and extensive **provenance testing** is generally required to identify superior provenances (Eldridge et al. 1993). Biotechnological tools, such as **chloroplast** and total **genomic DNA** assessment, can aid understanding and interpretation of the variation patterns and genetic histories of tree species (Cavers et al. 2004).

Forest red gum (*Eucalyptus tereticornis*) is a widely- and discontinuously-distributed species pollinated by insects and possibly birds and other animals, so some pollen might be widely dispersed. It occurs from coastal southeastern Victoria, as an isolate, through eastern parts of New South Wales and Queensland to about latitude 15 ^{0} N and in parts of southeastern Papua New Guinea. Like many species, it mainly 'showers' its seeds around each parent tree where progeny will grow close to one another and the parents. Forest red gums growing near rivers and streams may have some seed transported long distances. Such species have complex patterns of geographical, genetic variation related in part to environmental selection, discontinuities and diversities of pollen and seed flow, random factors, etc. They also exhibit variation among and within the offspring of individual seed parents. Species with other characteristics of distribution and breeding system may have different patterns of variation. Some species with very limited distributions have little or no provenance variation; and species that breed by **self pollination** may have very limited variation within families.

The common existence of important genetic variation within a species at the levels of **provenance**, **parentage (family)** and **individual** provides the breeder with opportunity to select at all these levels. Often, however, breeders have had to begin tree improvement programs by phenotypic selection and seed collection (**mass selection**) in a plantation of trees of a single or few provenances (of unknown relative productivity) and comprising trees derived from the bulking of an unequal and unknown amount of seed from an unknown number of seed parents. This primitive approach has succeeded for a number of traits with a number of species, an indication of a heritability greater than zero for those traits. However, it is relatively inefficient because it does not exploit provenance and family variation effectively. Nor is it efficient in using individual variation for, as mentioned, the phenotype of each selected tree is the combined reflection of a tree's genes and their interaction with the environment. These two components are inseparable unless the breeder can secure seeds from individual candidate trees, or replicate the candidates clonally, and rank them via well-designed progeny or clone tests respectively. As soon as possible, he/she should install well-designed **provenance**, **progeny** and **clone trials** (as appropriate), and use modern quantitative genetics, in order to identify truly superior provenances, families and individuals efficiently.

Tree **breeding methods** comprise **population improvement** or **hybridisation**. Each of these has its strategies, all aimed at accumulating genetic gains over breeding cycles (the shorter the better). Strictly, species and provenance selection are not breeding methods but activities that should precede the use of such. In tree improvement, some type of **propagation system** is used to mass-produce improved varieties developed by selective breeding. Examples include **seed orchards** (seedling, clonal); and **hedge gardens**, for the production of cuttings.

Using population improvement via selection and sexual reproduction, especially with some control of pollination, tree breeders have been very successful in genetically improving populations (Eldridge et al. 1993). For example, the progeny of culled, **clonal seed orchards,** established with selections from plantations of good provenances, can lift the productivity and quality of plantations dramatically. However, such orchard progeny are genetically relatively variable (due to differences in **breeding value** among the parent clones in the seed orchards, and to recombination and some mutation of genes in the crossings between these clones). Their use in plantations fails to utilise the individual genetic variation as a source of further gain. Extra gain in population mean and uniformity can be obtained where it is practicable to clonally replicate and test individuals, either from within superior families (preferably), or from broader populations such as orchard bulks or others, then select and use the best.

The 'package' comprising individual tree selection, clone testing, selection of superior clones, and mass vegetative propagation and deployment of the best, is known as **clonal forestry** (Evans and Turnbull 2004, Leakey 2004, and much earlier works cited therein). Usually it will be more expensive, but it offers the opportunity to maximise the gains from selection (in nature, in planted stands that are unstructured or in stands derived from pedigreed breeding), and to realise the extra gains more rapidly than via seedling propagation. Leakey 2004 outlines the conditions under which clonal forestry is an appropriate option.

<u>Thus, cloning is a propagation option, not a breeding method. It can be very effective in making use of proven superior individuals either in nature or developed by breeding</u>. Radke and Radke 2004 mentions the vegetative propagation methods potentially available for cloning forest trees commercially, and notes that the rooting of cuttings is the most practical.

The alternative propagation option and route to improved plantations, which by analogy may be called improved **seedling forestry**, involves mass selection or use of seed orchards to provide improved seed to produce seedlings for deployment. These approaches have often served well, and will continue to do so, in appropriate circumstances, e.g. where the biology of a species is not suitable for clonal forestry, commercial propagation technology is not yet available (hoop pine), requisite resources are lacking, or profitability is inadequate/negative.

Seedling forestry, with a pure species or hybrid, may be implemented using seedlings from bulked seed, or from individual, superior families (**family forestry**). The families may be of open- or control-pollinated seed. In the latter case especially, the seed obtained is often too limited in amount and/or too expensive for direct use. In such cases, the seed may need to be 'multiplied' by vegetative propagation (rooting of cuttings) from seedlings. This, clearly, results in the production of clones and provides the options of deploying either mixed, **unidentified clones**, or **identified clones**. The latter option can enable the identification of superior clones and families if samples of each are tested in well-designed trials (cloned progeny/family trials). If applied to a whole breeding population this procedure is known as **cloning the breeding population**. When the biology of a species is appropriate, cloning the breeding population can provide a number of benefits in an improvement program. Shelbourne 1991 p 315 suggested that cloning the breeding population "may well be the nearest thing to a free lunch that you're going to get", and real benefits have since been demonstrated by Snedden and Verryn 2004 with a breeding population of *E. grandis* established in South Africa in 1994.

Acknowledgements

I thank Drs Roger Arnold and Chris Harwood for comments on a draft of this article.

References

Cavers, S., Navarro, C. and Lowe, A. J. 2004. Targeting genetic resource conservation in widespread species: a case study of Cedrela odorata. For. Ecol. & Management 197:285-294.

Eldridge, K., Davidson, J., Harwood, C. and van Wyk, G. 1993. Eucalypt domestication and breeding. Clarendon Press, Oxford. 288 p.

Evans, J. and Turnbull, J. 2004. Plantation forestry in the tropics. Oxford University Press. 467 p.

Falconer, D. S. 1989. Introduction to quantitative genetics. Third ed. Longman. 438 p.

Leakey, Roger R. B. 2004. Clonal approaches to hardwood forestry in the tropics. Working Paper in: Bevege, D.I., Bristow, M., Nikles, D.G. and Skelton, D. (eds). 2004. 'Prospects for high-value hardwood timber plantations in the 'dry' tropics of northern Australia'. Proc. of a Workshop held 19-21 October, 2004, Mareeba, Queensland. Published as a CD ROM by Private Forestry North Queensland Association Inc., Kairi, Qld.

Radke, P. and Radke, A. 2004. Plantation improvement by clonal propagation – an overview of the latest technology in Australia. Working Paper in: Bevege et al. 2004 (as cited above).

Shelbourne, C. J. A. 1991. Genetic gains from different kinds of breeding population and seed or plant production population. p 300-317 in Vol. 1, Proc. IUFRO Symposium "Intensive forestry: the role eucalypts". Durban, South Africa, 2-6 September, 1991.

Snedden, C. L. and Verryn, S. D. 2004. A comparative study of predicted gains for selection from a cloned breeding population and the implications for deployment. p 137-144 in Borralho et al. (eds) 2004. Proc. of IUFRO Conf. "Eucalyptus in a changing world". Aveiro, Portugal, 11-15 October 2004.