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THE BREEDING STRATEGY FOR RADIATA PINE IN NEW SOUTH WALES
PART II - PROPOSED OPERATIONS

BY

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Forestry Commission of New South Wales
SUMMARY

This Breeding Strategy details proposed courses of action which will enable the Forestry Commission of New South Wales (F.C.N.S.W.) to manage its resources of radiata pine genotypes such that the genetic quality of planting stock can be improved efficiently.

1. Principles and Objectives

The Strategy is based upon several principles. The most important of these include: continuity of operations, so that the generation interval, and delays in bringing improved material into routine production, are minimised; a hierarchy of populations, including Gene Pool, Breeding Population and Production Population, to help preserve genetic diversity in the long-term and to give short-term gains in routine plantations.

The main objectives of the Strategy are to improve the primary traits of volume, stem straightness and branch quality in plantations, as well as stand health (especially in areas prone to disease such as Dothistroma), and to maximise gain per unit time. Realisation of this gain is to be achieved by a prompt transfer of proven genotypes to Production Populations. Wood basis density will initially be maintained above a level of 355 kg m\(^{-3}\) (whole tree density) in Breeding and Production Populations, through the inclusion of only advanced-generation selections above this level in Breeding Populations and seed orchards.

2. The Gene Pool Population

The Gene Pool is the lowest level of the hierarchy of populations, with its main purpose being gene conservation, to provide a store of genes of the unimproved populations which may be lost during improvement, and also as genetic defences against possible future diseases or pests. The most important section of the Gene Pool is the plantings of genotypes from the native populations, derived mainly from seed collections in 1978. This natural gene pool will be maintained as a resource to underpin the Breeding Populations, although detailed proposals for its development still need to be worked out in co-operation with other breeders in Australasia.

The other section of the Gene Pool consists of first-generation selections and their offspring, planted in clone banks and progeny tests in N.S.W., notably the International Gene Pool Trials. Selections represented as ramets in clone banks will be maintained in this form. Genes of more recent first-generation selections from N.S.W. and families in tests such as the Gene Pool Trials will be maintained in seedling stands over several sites. The Gene Pool and the base breeding population (from which Breeding Populations are selected) will contain a relatively high proportion of N.S.W. selections, and be somewhat different from those of other radiata pine breeding organisations, thus helping to maintain a diverse overall gene pool of the species.

3. The Breeding Population

The Breeding Population is the middle level of the hierarchy. The basic aim of the Strategy, of improving the genetic quality of plantation stock, depends on managing this Population for the cumulative buildup of favourable genes in useful traits. At least 300 unrelated second-generation selections (parents) will ultimately be incorporated into the total Breeding Population. These will be allocated to two separate Breeding Populations, aiming to develop genotypes suitable for planting on different site types, based primarily on soil parent material.
The Granite/Sedimentary Breeding Population will develop genotypes adapted to areas with granite/granodiorite and medium to high fertility sedimentary parent materials, and will initially be composed of second-generation selections from progeny tests on these sites. There is evidence of genotype x environment interaction for growth on these sites, so selections from apparently interactive families will be utilised, along with those from families superior on both site types.

This Breeding Population will be divided into about 13 sublines of 30 second-generation selections each, to help control inbreeding. Inbreeding will build up within sublines, but outcrossed seed can be produced in seed orchards composed of selections from different sublines. These sublines will include second-generation selections from N.S.W. progeny tests (seven or eight sublines), from South Australian progeny tests (two sublines), from New Zealand (one subline), and possibly selections in natural Californian families (three sublines). Mating designs to produce the second-generation Population will vary between sublines. In the first four, incomplete polycrossing will probably be used, so that general combining ability (GCA) estimates can be obtained for clones already in Windamere Seed Orchard (see later). Single-pair mating will be used in the other sublines, as this is operationally simple and likely to give satisfactory gains. A small supplementary diallel will be used in those sublines containing selections from interactive families, to generate extra full-sib families which may prove to be well-adapted specifically to 'granite' or 'sedimentary' sites.

A supplementary polycross mating including all selections in the sublines will also be attempted, to obtain GCA estimates for them, which will indicate the most promising to include in future control-pollinated seed orchards.

The full-sib families in the second-generation Breeding Population will be planted out in replicated tests over four sites on both geological types. A two-stage assessment will be used to select third-generation parents at about 8 to 10 years, for diameter, stem straightness, branch quality and possibly wood density. Selection will be based on a combined selection index, integrating family and individual tree data for assessed traits, and will be mainly within-families.

A separate Dothistroma-Resistant Breeding Population will also be created, to develop genotypes for areas prone to Dothistroma needle blight, mainly on the Northern Tablelands, and areas of basic parent material (basalts, gabbros etc.) in northern and central parts of the State. Second-generation selections will be taken from vigorous and well-formed families in progeny tests which have been subject to Dothistroma infection, and some others on basic geology. Initially, 93 such selections will be included, along with the 28 New Zealand clones used in the Granite/Sedimentary Population.

A simple open-pollinated mating design will be used. The 121 clones will be planted out as grafted ramets in a clonal stand adjacent to Walcha Seed Orchard. Seed will be collected from each clone after about eight years and used to establish the single, un-sublined Breeding Population over two sites subject to Dothistroma, consisting of a family block and a small progeny test at each site. Selection of third-generation parents will be within families, from one of these plantings, while selection for seed orchards will be between and within families, based on a multi-trait selection index. A new clonal stand will be established using the third-generation selections, additional selections from younger progeny tests, and possibly some from New Zealand, giving a total of about 200 unrelated selections.
4. **The Production Population**

This is the top level in the hierarchy, and includes clones of the very best genotypes from the Breeding Populations, which will produce seed or cuttings for routine use. The two types of Production Population proposed include seed orchards of high-GCA selections, producing seed, and special-purpose crosses from which cuttings will be mass-propagated.

The present Production Population is based on four clonal seed orchards, three of which have only recently been established. The one old orchard (Vulcan) has had generally mediocre seed yields in the past, but will need to be retained for at least another seven or eight years, until the younger orchards become productive. Windamere Orchard is expected to produce seedlings suitable for granite and sedimentary sites. Tallaganda and Walcha Orchards comprise vigorous, well-formed clones of presumed *Dothistroma* resistance.

Seed for granite sites will be supplied partly by Vulcan Orchard, and possibly by some clones in Windamere Orchard. It is likely that one or two new orchards will be required by the early 2000’s; control-pollinated (c.p.) orchards are proposed. Adequate seed for sedimentary sites will probably be supplied by Vulcan and Windamere, the latter until about 2010. Seed for basalt and *Dothistroma*-prone sites will be supplied by Tallaganda and Walcha Orchards until about 2010.

Existing seed orchards will need intensive management to ensure adequate seed yields and economically viable operation. It is proposed to write a management plan for each of them. Culling, to remove clones with poor GCA for growth, form and disease resistance, and/or poor cone yields, is an operation which will be most necessary in Walcha Orchard, which was established using many clones of unproven *Dothistroma*-resistance. This culling will depend on obtaining GCA estimates for the clones. Testing for GCA is also necessary for Windamere Orchard clones, to determine those adapted to different sites and to remove poor performers.

The existing orchards were established assuming future management as open-pollinated orchards, with little or no crown manipulation beyond perhaps a limited amount of pollarding. This type of management will be pursued in most cases, despite some disadvantages, except for a limited amount of supplementary mass-pollination in Windamere and Walcha Orchards. Cultural treatments such as fertiliser and irrigation will be applied to the new orchards to optimise yields. These regimes will require a degree of experimentation to determine the most suitable. Maintenance, such as weed control and fire protection, will be rigorously pursued.

Seed orchards established after the early 1990’s will most likely be control-pollinated, employing hedged ramets and artificial application of pollen. This type of management allows greater control over the pedigree of planting stock, and the development of special breeds for particular sites or purposes, by pairing parents of known high GCA. These orchards will be sited in areas likely to promote abundant female flowering and conelet survival, with management techniques based on experience of other managers of such orchards in Australia and New Zealand.

Extensive seedling seed orchards (ESSO’s) are also advocated. These would be established using bulked seed of superior open- and control-pollinated families, over two sites. A heavy early thinning would remove most families, and give seed of fairly high genetic quality as well as timber. Establishment of these facilities will have a lower priority than the development of other sections of the Production Population and the Breeding Populations.
The use of rooted cuttings is proposed under the Strategy, mainly as a means of bringing special genetically superior material into production earlier, as well as propagating genotypes adapted to particular sites. Expensive seed from seed orchards may also be able to be bulked up by mass vegetative propagation from seedlings. The primary aim, in the earlier stages of the Strategy, will be to develop genotypes whose cuttings are able to survive and grow well on three types of problem site.

The most immediately important of these is improved pastures, which have nutritional imbalances which cause poor growth and/or form in seedling trees. A range of approaches is suggested, from the propagation of field-select cuttings from seedlings of promising performance in routine plantations on this site type, through the mass vegetative propagation from seedlings of families showing promise in tests already established, to the production of full-sib families by crossing promising first-generation clones, with field testing and cuttings propagation of the best families. The infusion of genes of the native Guadalupe population into these programmes is also proposed, as this population generally has good stem-form, even on ex-pasture sites. This programme could be commenced in the near future. In addition to the development of new local selections for these sites, co-operative testing of interstate selections will be continued.

The development of *Dothistroma*-resistant families and clones which can be propagated by cuttings is also proposed, and this work has begun, with clonal trials already in the field. Some specific crosses will also be produced, using first-generation selections of apparent resistance and superior growth and form.

A project of lower priority will be the development of families and clones suitable for low-phosphorus sites, where the main selection trait is growth rate. Suitable trials exist on these sites, from which suitable material can be selected in the next few years.

The development of a cuttings-based Production Population to service the great bulk of planting areas presently catered for by seed orchards is not expected for many years. Specialised facilities would be needed which were capable of producing several million cuttings. However, a small-scale development of such facilities will be needed in the near future, to permit implementation of the proposed strategies for the problem sites, and to augment special seedlots from seed orchards.

5. **Demonstration Plantings**

These plantings are proposed, to demonstrate to forest managers the realisable gains from breeding of routine and more specialised planting stock. They will be small replicated blocks, allowing a visual comparison with similar blocks of unimproved or less-improved stock. Some of these plantings already exist, which will indicate gains from older seed orchards in N.S.W., other Australian States and overseas. Demonstration plantings of stock from newly-established and future orchards and cuttings programmes will be planted as opportunities arise.
6. Possible Achievements

If operations under the Strategy are carried out as planned in the Breeding and Production Populations from the time of writing (January, 1989), the genetic resources and facilities listed below should be available to the Commission.

**Granite and Sedimentary Sites**

- Commercial-scale seed production from Windamere Seed Orchard: 1993-94.
- Clones for new control-pollinated seed orchards (backwards selections on GCA, from sublines 1 to 5): 2000.
- Clones for new seed orchards (backwards and forwards (3-generation) selections from Sublines 1 to 5): 2004-5.
- Clones for new seed orchards (backwards selections from Sublines 6 to 10 or 11): 2007.
- Clones for new seed orchards (forwards selections from Sublines 6 to 10 or 11): 2011.
- Third-generation selections from Sublines 6 to 10 or 11 (and perhaps sublines of native material): 2011.

**Dothistroma-Prone and Basic Rock Sites**

- Commercial-scale seed production from Tallaganda Seed Orchard: 1994-95.
- Commercial-scale seed production from Walcha Seed Orchard: 1995-96
- Culling of Tallaganda Seed Orchard: 1998
- Culling of Walcha Seed Orchard: 2000-02.
Cuttings Production for Improved Pasture Sites

a) Field-select cuttings from routine plantations on pasture sites: as soon as cuttings raising facilities established.

b) Cuttings of promising first-generation clones (seed from o.p. seed orchard): as in (a) above.


d) Cuttings of hybrid N.S.W. x Guadalupe full-sib families: 1995.

Cuttings production for Dothistroma-Prone Sites

a) Cuttings of proven resistant clones (supplied by C.S.I.R.O. if possible): 1990;


Cuttings Production for Low-phosphorus Sites


b) Cuttings of full-sib N.S.W. families: 1994-95.
INTRODUCTION

A breeding strategy for a tree species is essentially a 'battle plan' to assure near-optimum genetic gains in the species, in the short- and long-term, in the face of many uncertainties (Shelbourne et al., 1986). The strategy for any breeding programme represents a carefully integrated series of activities designed to deliver maximum genetic gain.

Genetic improvement of radiata pine by the F.C.N.S.W. has been under way since 1958. During this time, various short-term working plans for improving the species have been written, and largely implemented. However, none of these plans was published as F.C.N.S.W. policy on radiata pine tree improvement.

None of these previous plans addressed itself to the important issue of the long-term flow of selected genetic material through breeding and production populations, such that the best genotypes could be used efficiently as stock for future plantations. A great deal of meticulous work has been done by tree breeders throughout Australia to select first-generation plus trees and establish seed orchards. However, most breeding programmes, including that in N.S.W., did not proceed into future generations of breeding in a planned way, thus losing time and potential genetic gain in plantations.

The importance of detailed long-term planning in radiata pine improvement has been recognised only fairly recently in Australia. The current high level of interest in breeding plans was stimulated largely by the publication of the South Australian Breeding Plan by Dr. P. Cotterill (1984). This Plan has set a standard for other breeders of the species. It embodies the important principle that such plans should be published documents, so as to attract advice from other breeders, and to benefit from their experience.

The present Tree Improvement Strategy was written in recognition of the need to plan and organise breeding operations for radiata pine in N.S.W. for the next 20 to 25 years, and to include these plans in a formal published documents. Part 1 of the Strategy (Johnson, 1987) gives a history of radiata pine improvement activities by the F.C.N.S.W. since 1958, and discusses gains achieved through the use of genetically-improved growing stock in this State, as well as listing genetic resources available to the breeding programme. This Part (Part 2) of the Strategy details general courses of action which should enable the F.C.N.S.W. to manage this large resource of genotypes of the species presently available to it, so the genetic quality of planting stock can be improved most efficiently on a broad scale.

It is important to understand that this, or any, breeding management strategy is only a starting point for actual tree improvement efforts. It incorporates practical knowledge and theory available at the time of its writing (in this case, January, 1989). The evolution of both theoretical and practical knowledge in radiata pine tree improvement is presently very rapid, especially in aspects such as selection and mating strategies, and in clonal propagation and seed orchard design. This Strategy is based on sound principles of tree gene resource management, so it will be possible to incorporate later improvements in theory and operational methods to increase genetic gains.
BASIS OF THE STRATEGY

1. **Principles**

   a) The overriding principle of the Strategy is that it should serve the general and specific needs of the F.C.N.S.W. with respect to tree improvement.

   b) Breeding operations should be carried on continuously, and strictly to a timetable of operations. This is a paramount requirement, since any loss in the momentum and direction of breeding operations can result in a serious lengthening of the breeding generation interval and cause delays in bringing genetically-superior material into production.

   c) The Strategy should be based on a hierarchy of populations of genotypes. The levels in this hierarchy are: Gene Pool Population, Breeding Population and Production Population. This structure of populations should permit considerable short-term gains to be achieved in routine plantations while genetic diversity is maintained in the long term in the Breeding Population and Gene Pool.

   d) The Strategy relies on a large first-generation base breeding population consisting of several hundred plus tree selections from wild stands and/or unimproved plantations of the species, to give a widely-adapted total population at the next level of the hierarchy.

   e) The Strategy is designed so that workloads are practicable. The level of manpower committed to *P. radiata* tree improvement is assumed to remain at present levels, for the foreseeable future.

   f) The detection and quantification of genotype x environment interactions is of prime importance, considering the wide range of site conditions prevailing in present and future radiata pine plantations in N.S.W. Where site constraints are determined, the aim will be to develop Breeding Populations that are specifically adapted to major site types.

2. **Objectives**

   a) The primary objective of the Management Strategy is to develop Breeding and Production Populations which will lead to:

   . Increased wood volume production per area in routine plantations.
   . Improved average stem straightness and branch quality in plantation trees.
   . A reduced incidence of stems with malformations such as forks and ramicorns.
   . The maintenance of juvenile wood basic density in plantation trees at or above a minimum level, tentatively set at 337 kg m\(^{-3}\).
   . Routine plantations free of severe disease or nutritional problems.

   Selection of genotypes to be included in the Breeding and Production Populations, in the earlier stages of the Strategy at least, will be for those traits likely to result in an end-product useful to a wide range of wood-using industries: fast growth, straight stem, fine branching, and whole-tree wood basic density above 355 kg m\(^{-3}\) (see Section on Selection Criteria for derivation of these minimum basic density levels).
It needs to be remembered that the greater the number of traits to be improved, the smaller will be the gains in each trait. This is particularly true where traits are negatively correlated, e.g. growth and wood density in radiata pine. In selection in early generations, greater emphasis will be placed on more important traits, particularly vigour and stem straightness.

b) The next objective is maximum realised genetic gain per unit of time in plantations, rather than maximum gain per generation.

c) Families proven to be of very high genetic quality are to be advanced from the Breeding Population to the Production Population as rapidly and efficiently as possible so that potential genetic gain may be quickly realised in future plantations. To achieve this, the siting and management of facilities (e.g. seed orchards, breeding arboreta) for mass-producing seed or cuttings of desirable clones must be close to ideal.

d) Production Populations aim to deliver annually at least enough seeds and/or cuttings to establish the F.C.N.S.W.'s own plantation areas.

e) The Strategy aims to be flexible, enabling the incorporation of new ideas and technology. Detailed planning will initially be done for the next 22 years (1989-2021).
SELECTION CRITERIA

1. Traits to be Improved

Within the general Principles and Objectives set out above, the selection of superior trees should be based on as few traits as possible, to allow maximum gain in each trait. Traits to be improved through breeding should be desirable for a wide range of end products and have appreciable additive genetic variance, that is, be both variable and heritable (Brown and Matheson, 1983). Such desirable traits are discussed below:

(a) Vigour is universally desirable, and the most important trait of radiata pine to be improved in N.S.W. since it determines the volume of wood produced per area of plantation and to a large extent the royalty value of individual trees, and therefore the viability of tree improvement programmes.

In the past, vigour has been assessed as diameter at breast height over bark (dbh) and total height in progeny tests, at ages of up to 12 to 15 years. These measurements have sometimes been combined in a simple volume approximation such as \((\text{dbh})^2 \times \text{total height} (\text{d'h})\).

Diameter of radiata pine has been found to have a low to moderate individual heritability e.g. 0.07 to 0.23 in South Australian and Victorian progeny tests (Cotterill and Zed, 1980; Dean et al., 1983) and 0.18 in one N.S.W. progeny test aged seven years (Ades and Johnson, 1984). Very strong positive genetic correlations are observed between dbh and d’h and to a lesser extent between height and d’h, for example 0.99 and 0.93 respectively (Dean et al., 1983). Reasonably strong genetic correlations occur between height and dbh (e.g. 0.87 - Dean et al., 1983).

Two factors favour the measurement of diameter only, and not height, at the final assessment of progeny tests. One is the very strong positive genetic association between diameter and volume (measured as \(\text{dbh}^2 \times \text{height}\)). The other is the low cost of measuring diameter compared with measuring height. Little additional information is therefore gained from a large investment of time and labour in height assessment, unless some site factor is depressing height development or unduly increasing diameter development independently of height (e.g. high nitrate levels in old pastures).

In view of these considerations, selection for vigour under this Strategy will be for diameter only, unless known environmental effects are influential on either trait.

(b) Stem straightness. This trait is perhaps the second most important after vigour, since improvements in straightness would benefit all wood-using industries: straight logs reduce handling costs in the forest, give a higher percentage return of millable wood, and generally contain smaller amounts of severe compression wood (Shelbourne, 1970).

The individual heritability of stem straightness has been found to be moderate in progeny tests in New Zealand and Australia (0.12 to 0.28 - Bannister, 1980; Cotterill and Zed, 1980; Dean et al., 1983; Matheson and Raymond, 1984). In 12 to 15 year old open-pollinated progeny tests in N.S.W., values of 0.24 to 0.39 were calculated (Johnson, 1985). Stem straightness has been found to be favourably genetically correlated with growth in radiata pine, so that selection for fast growth will also tend to lead to straighter stems (Cotterill and Zed, 1980).
A visual scoring system for stem straightness using a scale of 1 to 6 has been suggested as a standard to be used by all Australian breeding organisations (Dr. P.P. Cotterill, C.S.I.R.O. D.F.R., pers. comm.), since the even number of possible scores can lead to a more normal distribution of data than the 1 to 5 score originally proposed by Eldridge (1974). This scoring system has been used in N.S.W. since 1982 and will continue to be used, for the primary purpose of ranking families in progeny tests.

Objective measurement of separate stem straightness traits is possible, but it is very costly and would probably not give any practical advantages over subjective, composite scoring in ranking families. However, an objective composite scoring system for stem straightness in progeny tests is necessary for studies comparing performance across sites (including genotype x environment studies). A system, probably using a scale of 1 to 6 or 1 to 8, will be developed early in the period of the Strategy, whereby each tree will receive a score reflecting its absolute standard of straightness, in addition to the site-specific score already in use.

Stem straightness can only be assessed reliably after trees are at least four or five metres in height.

(c) Branch quality is a trait of lesser importance where logs are used for pulping, but is important for sawn timber.

Branch quality embraces several traits of branching, including branch size (diameter), branch angle and branching habit (whether uni-nodal or multi-nodal). A flat branch angle is considered desirable for all end-products because, with steep-angled branches, there may be encased bark on the upper side of the knot, with compression wood in the stem below (Shelbourne, 1970). The multi-nodal branching habit is favoured where the end-product is structural timber, as is small branch size, since both characteristics result in a higher bending strength in timber.

The individual heritability of branch diameter in radiata pine has been found to be low moderate (0.15 to 0.21 - Bannister, 1980; 0.06 to 0.32 - Cotterill and Zed, 1980); that of branch angle is moderate to high (0.08 to 0.43 in New Zealand - Bannister, 1980; 0.18 to 0.33 in South Australia - Cotterill and Zed, 1980), while that of branching habit is high to very high (0.49 in New Zealand - Bannister, 1980; 0.47 to 0.53 in South Australia - Cotterill and Zed, 1980). The genetic correlations between all of these traits have been found to be favourable, with the result that selection for reduced branch diameter, for example, will lead to a less acute (steep) branch angle and more branch clusters (Cotterill and Zed, 1980).

Adverse genetic correlations have been observed between growth traits and branch diameter or branch angle, but favourable correlations between growth traits and multi-nodal branching habit (Cotterill and Zed, 1980). Branch quality has been assessed since 1982 using a six-point score combining both branch diameter and angle. This method will be used in future to rank families in tests, along with a count of the number of whorls between one and six metres up the stem. However, due to the very high heritability of branching habit and its favourable correlations with branch diameter and angle, it may be more efficient to improve branch quality by selection on branching habit alone. This approach is currently being considered in New Zealand (R.D. Burdon, New Zealand FRI, pers. comm.).

As in the case of stem straightness, an objective scoring system for integrating branching traits will be developed, to give data usable in special research studies.
(d) Malformations. These include mainly forks and ramicorn branches. Such malformations are undesirable because they result in a wastage of timber where they occur, create weak points in the stem which may break in strong winds or heavy snowfalls, and affect the strength of timber.

They are complex traits which may have several causes: genetic, physiological and environmental (e.g. nutrients, birds, wind damage, etc.). Forking has been found to have a very low individual heritability (0.02 to 0.04) and ramicorn branches a low heritability (0.11 to 0.12) in South Australian progeny tests (Cotterill and Zed, 1980). Selection on progeny test results (family means) would therefore be necessary to substantially improve either of these traits. Preliminary culling of families showing a very high incidence of malformations may be sufficient to improve these traits to acceptable levels in breeding populations. This approach will be followed in family selection for the Breeding Populations in N.S.W.

The presence or absence of forks and ramicorns was scored in earlier progeny test assessments, over the whole length of the stem. More recent assessments have used an actual count of these features. This latter procedure will be continued under the Strategy, since the counts tend to be slightly more heritable than scores (Dr. P.P. Cotterill, C.S.I.R.O. D.F.R., pers. comm.).

(e) Wood quality. Basic density (BD) is the only wood property which will be considered at the outset of this Breeding Strategy. It is one of the principal features determining the quality of radiata pine wood for a wide range of end-uses, including veneer, sawn timber, pulp and paper. Increasing BD to a certain level results in a higher-quality product for all these end-uses (Harris et al., 1975). Further increases in BD above a level of about 520 to 530 kg m\(^{-3}\) (mean whole-tree BD) are perhaps of little economic importance, at least in sawn timber. In fact, radiata pine trees at or above this level of mean BD would probably rarely be encountered in existing plantations in N.S.W.

The elimination of low-density corewood (juvenile wood) in breeding stock would be advantageous for all end-products, and higher-density corewood would increase the mean density of logs and effectively reduce undesirable within-stem density gradients.

Density has been found to have a very high individual heritability in several studies (0.55-0.56 in New Zealand - Shelbourne et al., 1972; 0.33-0.56 in Victoria - Dean et al., 1983). Strong negative genetic correlations have been found between wood density and growth traits. Because of these, it does not appear to be possible to achieve substantial simultaneous gains in both volume and density from recurrent selection in radiata pine. However, it is possible to achieve very good gains (of about 17%) in growth and form while holding density constant at its present level (Dean et al., 1983).

It is important to set an acceptable minimum level for BD of plus trees used in breeding operations. At an average knot size of 40 mm, sawn timber from mature trees will reach the lower end of the F5 Stress-Grade at a mean whole-tree BD of about 355 kg m\(^{-3}\) (Grant et al., 1984). This figure has been found to correspond to a juvenile wood BD (rings 1 to 12) of 337 kg m\(^{-3}\) in a sample of 60 30-year old trees from six plantation sites in N.S.W. (Wilkes, 1988).

The main problem in estimating corewood BD in progeny tests is one of cost. Accurate methods such as laboratory analysis of increment cores are slow, and therefore expensive. Rapid methods of density screening, such as the pilodyn and the torsiometer, can be applied economically to large numbers of trees but they only sample a few of the outer growth rings, so density gradients through the stem cannot be estimated (Cameron et al., 1981). The other major problem with pilodyn and torsiometer measurements is that they have a low correlation with actual density, even for the outer rings, and cannot accurately
rank individual trees for density (P.P. Cotterill, C.S.I.R.O. D.F.R, pers. comm.). These techniques are thus of limited value for selection purposes, the best (pilodyn) only being sufficiently precise to categorise families into high, medium and low-density groups (Nicholls, 1979).

The collection of intact 5-mm cores from pith to bark in young trees in tests and their analysis by the maximum moisture content method of Smith (1954) was seen as a reasonable compromise by Cameron et al., (1981). One core per tree was considered sufficient for individual and family selection, from the largest 20% of trees per family. This is still a large work-load, since several hundred trees may need to be measured in any one test.

Basic density has not been measured to date in progeny tests in N.S.W. However, all current and future second-generation plus tree selections proposed for use in Breeding Populations or seed orchards will be screened for BD, to ensure that they are above the minimum acceptable level of mean corewood density (337 kg m$^{-3}$). Trees having a BD below this level should not be used in future breeding. In addition, the mean juvenile wood BD of the population of plus trees used in the breeding programme will be maintained at or above 358 kg m$^{-3}$, corresponding to a mean whole-tree BD of 390, which is the overall mean for 200 30-year old trees sampled in N.S.W. by Wilkes (1988). Basic density is a very highly heritable trait (as previously discussed) and this relatively low level of selection should be sufficient to ensure that plantations of improved genotype will produce timber of at least F5 grade.

The study by Wilkes (1988) of the range of wood density in N.S.W. plantations has yielded a useful quantity of data as a basis for setting minimum individual and mean levels for BD in plus tree selections. The minimum limits of 337 kg m$^{-3}$ (for individual tree corewood) and 358 kg m$^{-3}$ (for the mean of the plus tree population) are considered reasonable objectives. The reliability of these figures will be tested over the next few years as more data are accumulated on density variation in N.S.W. radiata pine plantations.

2. Genotype x Environment Interactions

There are several examples in the literature of significant genotype x environment (GE) interactions in radiata pine in Australia. Windsor and Kelly (1971) reported significant differences between clones in Green Hills Seed Orchard, N.S.W., in both foliar boron and inorganic sulphur concentrations. Pederick (1972) found highly significant family x site interactions and large rank changes for early height growth for full-sib families over three sites in Victoria. In a trial of 30 open-pollinated families across 11 sites in southern Australia, Matheson and Raymond (1984) obtained significant family x site mean squares for all growth and form traits tested, and also large changes of rank between sites for several families.

Statistically highly significant family x site interactions and large rank changes between sites have also been found in the three Shelbourne Gene Pool trials in N.S.W., for diameter, stem straightness and branch quality assessed at 12 years of age. These trials cover a wide range of sites with respect to soil type and nutrition.

In a practical tree breeding programme it is of primary importance to determine the likely effects of significant interactions and rank changes over sites on realised genetic gain in breeding and production populations. Shelbourne (1972) proposed as a rule of thumb that if the interaction component of variance exceeds half of the family variance component in a progeny test, interactions are likely to have a serious effect on potential gains from selection.
and breeding. Matheson and Raymond (1984) consider that using selections from one site on another, even close, site is likely to cause some loss in potential gain. They propose a method of calculation of loss of potential gain (C) for both individual and family selection, and suggest that levels of C of over 5% and over 2-3% respectively, are likely to indicate serious losses of gain if selections are used ‘off site’.

Preliminary analyses of 88 families in the N.S.W. International Gene Pool Trials gave Shelbourne rule of thumb values of below 0.5 for all three growth and form traits. Values of C for family selection exceeded 5% only in the case of stem straightness, while values for individual selection all exceeded 3%. These results give some support to the principle of regionalising the breeding programme in N.S.W., that is, developing separate breeding and production populations for broad site types, as represented by the Gene Pool Trials. A similar conclusion was reached by Pederick (1972), who considered that more genetic progress would result from regionalised breeding programmes compared with a single large programme for all regions. However, Pederick (pers. comm.) has recently concluded, from analysis of data from progeny tests on four sites in Victoria, that the small extra potential gains obtained by a change to breeding in regional zones would not be justified, due to the uncertainty of extra gains and the additional resources needed to operate regional programmes.

Matheson and Raymond (1984) concluded that “the most efficient solution to the problem of interactions” would be to maintain a unified, Australia-wide breeding population of widely-adapted families. ‘Interactive’ families would be identified and excluded from this larger population (possibly to be utilised in appropriate local regions).

A breeding strategy that can utilise GE interactions to advantage to maximise genetic gain in the breeding population is the ideal, although it is likely to be more complex and costly than a single breeding population approach. Data from progeny tests established in N.S.W. between 1964 and 1974 are being analysed for family x site interactions using a genetic correlation analysis approach (Burdon, 1977). The results of this study, together with earlier studies, as mentioned, should give a firm basis for deciding whether regionalised breeding populations are really appropriate for N.S.W. in the long-term. They should also give some indication of the best way to construct regionalised breeding populations, if these are required. The approach proposed under the New Zealand radiata pine Breeding Plan (Shelbourne et al., 1986) is to establish regionalised (or special purpose) seed orchards, if necessary, containing clones adapted to particular sites, without subdividing the breeding population by regions.

It will be important in any study of GE interactions to find out which environments are contributing most interactions, and why they are.

3. Age of Final Progeny Test Assessment

It is generally accepted that radiata pine progenies can be ranked accurately for assessed growth, form and wood traits at ages of eight years and above. Brown and Matheson (1983) suggest assessment when trees are 12 or more metres tall (about eight to ten years old for radiata pine on good sites). In the South Australian Breeding Plan (Cotterill, 1984) measurement of progeny tests is planned at 7.5 years after planting, when trees are expected to average 14 metres tall. Burdon et al. (1977) warn against too early a selection, since the comparative expression of genotypic differences in the juvenile and mature stages is often uncertain, especially because of distortions arising from competition effects. In the New Zealand Breeding Plan (Shelbourne et al., 1986), a final assessment for growth and form traits is proposed at eight to ten years, on fertile sites, and at proportionately later ages on slower-growth sites.
Previous final assessments of progeny tests in N.S.W. have been carried out at ages ranging from 10 to 15.5 years (Johnson, 1985). In future, final assessments will be done at ages of 8 to 11 or 12 years, depending on site quality.

Juvenile-mature correlation studies using results of tests planted in 1980-1981 will be carried out to determine the expected genetic gain from selection for vigour based on early measurements at five or six years, compared with later-age assessment (8 to 12 years).
MANAGEMENT OF THE HIERARCHY OF POPULATIONS

Genetic improvement and gene conservation are achieved under the Strategy via a hierarchy of populations, with three levels:

- Gene Pool Population.
- Breeding Population(s).
- Production Populations.

These Populations are run in parallel, with transfers between levels generally involving promotion from lower to higher levels (Burdon et al., 1977). The hierarchy, from Gene Pool Population (or gene resource population) through Breeding Populations to Production Populations also involves increasing levels of selection and genetic improvement, and decreasing levels of genetic variability and numbers of individuals; also an increasing specialisation of selection criteria (She1bourne et al., 1986).

1. The Gene Pool Population

This population is the lowest, or least improved, level of the hierarchy. The main purpose of the Gene Pool is for gene conservation, that is, to provide a store of genes present in the unselected populations, but which may be lost during selection and improvement of the species. This store of genes may become very important in meeting new selection criteria (e.g. resistance to new diseases, new nutritional demands or demands of new wood uses; Burdon et al., 1977; Franklin, 1972) which may arise over time. It is good insurance to maintain as large and diverse a gene pool as economically feasible (Burdon et al., 1977). Ideally the breeder should have available the full range of variability represented in natural stocks of the species, particularly as a genetic defence against pathogens (She1bourne et al., 1986).

(a) Description. The most important gene pool in N.S.W. is the plantings of seed collected in 1978 by a joint C.S.I.R.O. D.F.R. and New Zealand FRI team in the native mainland and island populations of radiata pine in California. This native gene pool should represent the genetic diversity present in the species (but which may not be present in existing plantations in Australia and New Zealand). It is expected that it will contribute additional new genes which will allow greater long-term selection responses in the Breeding Population, especially to extreme site conditions and resistance to diseases and pests (She1bourne et al. 1986).

Open-pollinated seedling progenies of 533 parent trees from all five populations were planted at two locations in Albury Forestry Region in 1980 and 1982. These form part of the base breeding population in N.S.W., from which selections for the Breeding Populations are likely to be taken. In addition there are extensive bulk plantings of the thirteen mainland sub-populations in Tumut District, Albury Region.

The other important gene pool is the store of genes represented in putatively unrelated first-generation plus tree selections from Australia and overseas, which constitute the balance of the base breeding population. There are 712 of these selections. The majority of new selections included in the population since 1980 are phenotypic selections in routine plantations in N.S.W., with a heavy emphasis on site types not sampled, or inadequately sampled, during previous plus tree searches in 1959-1973. Many of the first-generation selections will be discarded in future generations of improvement of the Breeding Population, so their genes should be stored for possible future use.
Most of the Australian selections are represented in gene pools which consist of ramets in clone banks. Propagation of first-generation parent trees by grafting into clone banks is the simplest way of preserving their genotypes (that is, their genes and the particular combinations in which they occur on the chromosomes) in perpetuity as a gene pool. Most of the older N.S.W. and A.C.T. selections have been repopulated into the younger clone banks in Albury Region (Helms and Lochinvar) over the past few years, and all new first-generation plus tree selections made in N.S.W. up to 1983 have been grafted and planted in one or other of these clone banks.

This clone bank approach to gene conservation has proved to be expensive, especially in terms of time, and adequate maintenance of the ramets required after planting has often been difficult to achieve, because of shortfalls in labour.

The great majority of the overseas selections are represented in gene pools which consist of offspring in progeny tests and special gene pool plantings, notably the International Gene Pool Trials in Wee Jasper, Gurnang and Nundle S.F.'s. These latter trials were designed to perform the role of progeny tests as well as gene pools.

(b) Proposed operations. The natural population gene pool will be maintained as a resource to underpin the Breeding Populations. The future use and regeneration of this gene pool will be specified in co-operative plans still to be drawn up between the F.C.N.S.W. and other breeding organisations, including the C.S.I.R.O. These plans should take account of the fact that, while these collections are of broad genetic bases, the inbred nature of much of the material and lack of selection under Australian conditions may make much of it unsuitable for contributing immediately to Breeding Populations (Shelbourne et al., 1986).

Under this Breeding Strategy it is proposed to discontinue the practice of propagating all new first-generation selections from routine plantations into clone banks, since this would divert valuable resources from operations more vital to the implementation of the Strategy, such as progeny testing the large number of new selections, controlled pollinations in the Breeding Populations, the development of seed orchards, and so on. (This proposal should not be confused with the propagation of second-generation clones, most of which are parents of the second-generation Breeding Populations, into clone banks; all second-generation selections will be represented in clone banks, and those proposed as parents in the Breeding Populations in a breeding arboretum as well - see later discussion.)

Instead, the type of low-cost gene pool used by the Southern Tree Breeding Association (STBA), as described by Cotterill (1984), is proposed. The gene pool will be established as bulked open-pollinated progenies of as many as possible of the first-generation plus trees represented in the base breeding population. This gene pool will be replicated over at least two sites of 20 ha each, for security, and will serve as a low-cost 'museum' to conserve genes present in the base population which may be discarded in advanced generations. It will store genes, but not gene combinations.

This section of the gene pool will be regenerated in future by the collection of open-pollinated seed from a random sample of trees at each site. There may be some loss of genes in this process, but Cotterill (1984) considers this risk to be small if about 10% of the trees are sampled. This seed collection should be delayed as long as possible, perhaps until final harvest, to maximise the rotation age of each gene pool planting. Earlier thinnings of the gene pool may be at random, to minimise the risk of loss of genes. However, some mild silvicultural selection in the thinning process would probably not lead to any serious loss of genes (Burdon et al., 1977).
First-generation clones already established in clone banks will be maintained, as they are a valuable resource. The ramets will be kept in a healthy, vigourous state as far as possible and protected from damage. They will be maintained, by topping (pollarding), at a height where the crown is easily reached from ground level or a low ladder. This is necessary because some of the ramets will be a source of pollen for controlled-pollinations in the breeding programme, and some of these pollinations will be carried out in clone banks. The parent trees represented in these clone banks will, in many cases, be included in the proposed low-cost seedling gene pool as well. The exception to this will be those clones of older (pre-1973) N.S.W. and A.C.T. selections for which open-pollinated seed from the ortets is no longer available. There are relatively few of these (about 100).

Second-generation parent clones have been planted out in Lochinvar Clone Bank since 1982. This Clone Bank is now nearly full, and there are still several dozen second-generation selections to be cloned for the Breeding Population. A second clone bank will therefore be established, as a matter of priority, to contain all of these new selections, as well as a few ramets of each of the selections already in Lochinvar Clone Bank. It is wise to establish these important clones over two sites, for security. Many of the ramets will be used as sources of pollen for both Breeding and Production Populations, and much of the controlled-pollination work will also be carried out in the clone banks. The loss of any of the clones would be a severe blow to the breeding programme.

The new clone bank would not need to be as large as the Lochinvar Bank - about two or three hectares would suffice. Three or four ramets per clone will be planted as the backup for clones already in Lochinvar. New clones will each be represented by six ramets, planted at 2.5 x 5 metres.

The International Gene Pool Trials and the 1974 progeny tests will need silviicultural thinning in the near future; the loss of genes in this process would be minimised by retaining equivalent numbers of trees per family.

These operations will result in a gene pool and base population on which the Strategy is to operate which contain a high proportion of N.S.W. selections. It is good sense to maintain gene pools in N.S.W. that are somewhat different from those of other organisations breeding radiata pine. This policy will aid in the maintenance of a more diverse overall gene pool among radiata pine breeders around the world. No single breeding operation has the resources to adequately conserve the total variability present in a species (Burdon, 1986). The option will be open for later injection of genotypes from other breeding programmes into the N.S.W. Breeding Populations.

2. The Breeding Population

The Breeding Population is the middle level of the hierarchy of populations. The basic aim of the Strategy, of improving the genetic quality of plantation stock, depends upon managing the Breeding Population for the cumulative build-up of favourable gene frequencies in generally-useful traits. Breeding populations consist of pedigreed families planted in tests, which have a dual role of yielding the individuals to form the later-generation breeding populations, and of giving family information to assist in selecting these individuals for mating (Shelbourne et al., 1986).

The total base breeding population under the control of the F.C.N.S.W. at the end of 1987 included a total of 1273 putatively unrelated first-generation selections. The great majority of these are represented by open-pollinated (on ortet or ramets in seed orchards) and/or control-pollinated progenies in progeny tests (see section on Gene Pool Population). Most of the control-pollinated progenies in tests are related as half-sibs. About 50 of the selections are first-generation plus trees in plantations, as yet not progeny tested.
The overall aim in management of the Breeding Population is to ultimately incorporate at least 300 unrelated second-generation selections (parent clones) into long-term breeding populations. These selections will be drawn from first-generation families proven superior for the major traits diameter, stem straightness and branch quality, and Dothistroma resistance where appropriate, by the performance of progenies in tests.

The number of 300 selections is proposed because, with a total population of this size, it should be possible to satisfy the short-term objective of achieving large genetic gains in early generations of breeding, as well as the long-term objective of providing a high limit of response in traits in the long term (Cotterill, 1984). Burdon and Shelbourne (1971) proposed a long-term breeding population of about 200 unrelated genotypes in New Zealand, while Cotterill (1984) recommended a second-generation population containing 400 unrelated parents in South Australia. The New Zealand radiata pine Breeding Plan (Shelbourne et al., 1986) proposes intercrossing among 300 to 400 selections from 15 series of families, in the Multinodal Breeding Population.

Following Principle (f) under this Strategy, it is proposed that second-generation selections will be allocated to a limited number of separate Breeding Populations, each aiming to develop genotypes well-adapted to a particular broad target site type, based primarily on soil parent material. Two major Breeding Populations will be developed at the outset of the Strategy. These will be known as the ‘Granite/Sedimentary’ and ‘Dothistroma-resistant’ Breeding Populations. The first of these is a combined Population and will be developed to produce genotypes adapted to either or both granite and sedimentary sites. The Dothistroma-resistant Breeding Population will be designed to serve Dothistroma-prone planting sites, and areas of basalt geology in the central and north of N.S.W. Descriptions of the Breeding Populations and proposals for operations within them are detailed below.

About 300 unrelated second-generation selections will ultimately be represented in the Granite/Sedimentary Breeding Population, and up to 200 in the Dothistroma-resistant Population, so that each is capable of improvement as a separate population in the long-term.

The general policy will be to utilise selections from progeny tests growing on similar geology to the target site type in plantations, on which genotypes produced in each Breeding Population will ultimately be planted. For example, selections included in the Granite/Sedimentary Breeding Population will be taken from tests on granite, granodiorite, shale or phyllite geology, and superior genotypes produced in each generation of breeding would be routinely planted on sites with the relevant type of parent material. There will be exceptions to this, as discussed in the separate Breeding Population sections.

There is a considerable overlap in the families to be represented in the various Populations. Many families performed very well over two or more site types; this is most evident in the International Gene Pool Trials. The Granite/Sedimentary Breeding Population will be composed mostly of selections from families which were superior in performance in tests over both these site types. A single second-generation plus tree will be selected over several tests in most of these cases. This policy will reduce the workload in setting up and managing this Population, and will allow a greater within-family selection intensity. Occasional apparently interactive families (which perform very well on only one of these two broad site types) will, however, also be utilised in this Breeding Population. This is explained in detail below.

On the other hand, selections for the Dothistroma-resistant Breeding Population will be taken specifically from tests in Glen Innes Region which have also been affected by Dothistroma. These selections will have demonstrated resistance to this disease, as well as superiority in growth and form traits.
(a) **Breeding Population for Granite and Sedimentary Site Types**

*(‘Granite/Sedimentary’ Breeding Population)*

(i) **Description of site type.** The target site types for this Population include mainly areas with granite or granodiorite parent material (Level 1 Parent Rock Codes 071 and 091 - Turvey, 1987) and soils of moderate to high fertility, and areas with shale, phyllite or schist parent material (Parent Rock Codes 051 and 061).

About 35% of the 153,000 ha of radiata pine plantations in N.S.W. as at March 1987 were on granite/ granodiorite site types. Most of this area is in Albury Forestry Region (about 45,000 ha), with smaller areas in Bathurst, Bateman’s Bay and Eden Regions. Past land purchases by the F.C.N.S.W., for pine planting are also of this type, the most significant area being Red Hill Station, Albury Region, which contains about 7,000 ha on granodiorite. Only relatively small areas on this geology are likely to be purchased in future.

Tree growth on the majority of this site type is generally good in areas of high rainfall. Some areas exhibit boron deficiency, especially in drought periods, which causes leader dieback and malformation of the stem. This deficiency is difficult to remedy by fertilising.

At this stage, it is also proposed to use genotypes produced in this Population for areas of mixed geology (including granodiorite, acid volcanic, basalt and gabbro parent materials) in Albury Region. Such areas are relatively small, climatically similar to the granodiorite sites in the Region and generally free of *Dothistroma* needle blight. Results of genotype x environment (GE) studies presently underway may indicate whether this policy should be amended.

Moderate to high-fertility sedimentary parent material (shales, phyllites and schists) areas occupy about 37% of the plantation area established to March 1987. About 80% of Bathurst Region plantations are of this type, with other major areas in Eden Region and western parts of Albury Region. This parent material is present in large areas of land purchased by the F.C.N.S.W., over the last few years, and will be the preferred type in future purchases in all the major pine-growing Regions.

Relatively minor areas of phosphorus- (P) deficient soils occur on phyllites and schists, especially in parts of Tumbarumba District, Albury Region. Several thousand hectares of land purchased by 2000 in Albury and Bathurst Regions are also likely to be on P-deficient sediments. Productivity in these areas may be dependent on the addition of P-rich fertiliser at establishment (Turner, 1984).

There are also a number of other site types of low fertility (low P), each relatively minor in area. These include areas with quartz sandstone and conglomerate (parent Rock Code 021), rhyolite (081), and trachyte and dacite (101) parent material, totalling about 12% of the current plantation area, mostly in Bathurst Region and Bateman’s Bay Region (Moss Vale District). Little if any future purchased land is likely to be of these types. At this stage, it is proposed to serve these site types also with genotypes produced in the Granite/ Sedimentary Breeding Population. Selection will be used in a special cuttings programme (see later discussion).

(ii) **Selection of the second-generation breeding population.** The selections (parent clones) proposed for inclusion in this Population are second-generation clones from progeny tests in the southern and central highland areas of the State. Part of the Population will be compiled in the near future, using 120 selections from open-pollinated (o.p.) and control-pollinated (c.p.) families superior for growth and form, in 11 progeny tests established in Albury, Bathurst and Bateman’s Bay Regions in 1962-1974, which have received a final assessment. These second-generation clones are being selected either on...
The basis of family rankings alone, with selection within the best families (six tests), or with the guidance of a selection index compiled using the programme RESI (Cotterill and Jackson, 1981; 1985), kindly provided by the C.S.I.R.O. D.F.R. (five tests). The proposed second-generation selections from these early tests include 115 unrelated first-generation parents, and represent 85 unrelated families (see Table 1).

Three of the 11 progeny tests already assessed (Q14102, Green Hills S.F., Wee Jasper Gene Pool Trial and Q14114, Wee Jasper S.F.), have mixed geology, including large areas of metabasic rock types, along with acid volcanics and granodiorite, so none is a true ‘granite’ site. However, selections from these tests are vital to help make up a viable Granite/Sedimentary Breeding Population, so they will be included. The three tests have more in common with the other five true ‘granite’ tests than with tests on basalts on the Northern Tablelands, being in the same climatic zone as the ‘granite’ tests, and normally free of Dothistroma.

In addition, 28 New Zealand 875-Series and 268-Series clones are presently held in Lochinvar Clone Bank, Batlow District. Twenty four (24) of these clones are second-generation selections in superior families of the 268-Series (875-clones), while four are original first-generation selections from the top-ranking six of the 588 selections in the 268-Series, for growth and form. These are high-quality selections, unrelated to any others in the base breeding population, and will be included in this Breeding Population (and the Dothistroma-resistant Population) from the outset of the Strategy.

Second-generation selections from the South Australian ‘Super 80’ Series of first-generation plus trees (500 selections tested, all unrelated to the present N.S.W. base population) are expected to be available to the F.C.N.S.W. by 1990-91 (Dr. D.B. Boomsma, Woods and Forests Dept., pers. comm.). About 60 of these are proposed for incorporation into this Breeding Population, to further expand the range of unrelated genotypes.

Further second-generation clones will be selected between 1990 and 1997, in 10 progeny tests planted between 1981 and 1987 on granodiorite parent material in Albury Region and sedimentary parent material in Bathurst Region, when these receive a final assessment. The tests contain a total of 349 unrelated open-pollinated progenies of N.S.W. first-generation plus trees (which are unrelated to the previous 120 selections) and 57 unrelated control-pollinated families. The best 90 to 120 unrelated families will be selected on the basis of multi-trait selection indices integrating the traits: diameter, stem straightness, branch quality and number of whorls of branches. The selection index programme RESI (Cotterill and Jackson, 1981; 1985) will be used. Within each of these selected families, the individual tree having the highest index value, together with an acceptable level of wood basic density, will be selected as a second-generation parent clone for the Breeding Population.

Additional selections may be made in the 1980 and 1982 progeny-provenance trials of natural population families in Albury Region, after these trials have been assessed for growth and form by 1990, employing similar methods to those described above. Because the parent trees were not rigorously selected, a comparatively small number of second-generation selections would be made in these tests, representing probably only about 90 of the 533 families tested. A policy on the use of this material at this stage in the Breeding Population will be determined in the light of general policy on the management of this part of the Gene Pool, which will be developed early in the Strategy period.

In this Breeding Population (and the Dothistroma-resistant Population), a limited degree of relatedness among second-generation selections will be accepted, with the proviso that no more than four selections with one parent in common will be used in the Breeding Population. In fact, this will probably only apply to the 120 selections from the 1962-1974
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1962-1974 tests (see earlier), in which half-sib relatedness among superior families is unavoidable due to the mating patterns used in some of these early tests. This policy is expected to lead to more genetic gain in the overall Population than the alternative of insisting on total unrelatedness among the 300-or-so selections.

The selection of second-generation clones in the 1962-1987 progeny tests is at an average between-family selection intensity (proportion of first-generation selections represented in the second-generation Breeding Population) of about 1:3.5. This is similar to the level of 1:4 recommended by Dr. P. Cotterill, C.S.I.R.O. D.F.R. (pers. comm.). A slightly lower intensity of 1:3 is being applied to the 11 tests already assessed. However, it is evident that a higher intensity could not be applied to the available first-generation selections in this part of the Population without restricting its size too severely. Later selections (from the 1981-1987 N.S.W. progeny tests) for this Breeding Population will be at an intensity of about 1:4. A high intensity of family selection (at least 1:6) will apply to the natural population progeny-provenance trials, for reasons as outlined above.

(iii) Structure of the second-generation breeding population. Second-generation selections (parent clones) for this Breeding Population will be allocated to 12 or 13 sublines of 30 parents each, with related selections included in the same subline. The main purpose of sublining is to divide the overall Breeding Population into groups, with matings permitted between the parents within each group (subline) but not between parent in different sublines (Burdon and Namkoong, 1983). In this way, sublines remain genetically unrelated to one another in advanced generations of breeding. Although levels of inbreeding will increase in each subline over time, outcrossed seed can always be produced from seed orchards established using ramets of unrelated individuals from different sublines.

The number of sublines required for the Population is largely a question of the number of unrelated clones required in advanced-generation seed orchards. Under this Strategy, it is proposed that highly-selected clones will be used from Breeding Populations for future clonal seed orchards. At the outset of the Strategy, the Breeding Population will be structured to allow the option of establishing open-pollinated or mass-pollinated seed orchards. Such advanced-generation orchards should contain at least 12 to 15 unrelated clones (Dr. D. Lindgren, Swedish Uni. of Ag. Sciences, Umea, pers. comm.).

In practice, future seed orchards in N.S.W. are most likely to be control-pollinated, possibly accompanied by mass vegetative propagation of plantation stock. In this case, the number of sublines required could be reduced to as few as four, or even two (Burdon, 1986). In any case, the proposed Population structure leaves the option of merging sublines in future generations if necessary, to give a few larger sublines.

Thirty (30) parent clones are proposed per subline. The question of how many parents are required in each subline is largely one of rate of inbreeding. The greater the number of parents, the less is the rate of increase of inbreeding within the subline. Sublines of 20 to 30 parents each are suggested for radiata pine breeding by Burdon and Shelbourne (1971). The Southern Tree Breeding Association (STBA) Breeding Plan employs 13 sublines of 30 parents each (Dr. D.B. Boomsma, S.A. Woods and Forests Dept., pers. comm.). The number of 30 parents proposed in this Strategy is regarded as workable, in that it allows the creation of sufficient sublines for seed orchard establishment, while keeping workloads in each subline at practicable levels (see later discussion).

These sublines will be compiled successively over about eight years, as different groups of progeny tests receive a final assessment. This has operational advantages, in that major operations which have to be carried out within sublines will be spread over different years, making them more easily achieved.
It is proposed to make up four sublines of 30 parents each from 1962-1974 progeny test selections, to be known as Sublines 1 to 4. Subline 5 will comprise the 28 New Zealand 268-Series and 875-Series clones. Two sublines are proposed of the South Australian Super-80 reselections (Sublines 6 and 7). Three or four sublines (Sublines 8 to 10 or 8 to 11) will be compiled using selections from the 1981 to 1987 tests, with 30 parents per subline.

Each of Sublines 1 to 4 will be composed as far as possible of parents from a common geographic origin; for example, selections from families of N.S.W. origin will be allocated to one subline, those of New Zealand origin to another subline, and so on. It is desirable to have sublines reflecting the regional origins of selections, to maximise genetic diversity across sublines. Selections from different States and countries are less likely to be related than selections from within any one region. This policy will make it easier to maintain unrelatedness between possible future large sublines which may be created by merging the proposed sublines.

Sublines compiled using selections from N.S.W. progeny tests (Numbers 1 to 4 and 8 to 10 or 11) will be made up of both clones from families with superior performance across granite and sedimentary site types, and clones from families which perform very well on only one of these site types (apparently interactive families), in the ratio of about 2:1 or slightly more. That is, in each subline of 30 parents, 20-22 will be from widely-adapted families, and four or five from each of 'granite-only' or 'sedimentary-only' families. The number of these interactive clones will probably vary between sublines, depending on the availability of families of each type. This policy will allow the incorporation of excellent clones apparently adapted to a specific site type into the Breeding Population, which would be discarded if only generally-adapted genotypes were utilised. It will thus be possible to develop a subset of specifically adapted superior genotypes within the Breeding Population if future research shows this to be advantageous - see below. (If not, many of these selections will probably still prove to be useful contributors to a generally-adapted Breeding Population.)

Two or three sublines (No’s 11 to 13, or 12 to 14), containing selections from tests of the native Mainland populations of radiata pine, will be necessary to make up the proposed total of 12 to 13 sublines. In this case, a separate subline of 30 parents from each of the Ano Nuevo, Monterey and Cambria populations is most likely. Results of provenance trials (Johnson, 1988) indicate that all these populations are likely to contribute superior genotypes to the Breeding Population, even though they are one generation behind the other selections in terms of genetic improvement.

(iv) Mating pattern in the second-generation breeding population. The Breeding Population will be regenerated after each generation of selection by controlled crossing of the parent clones within each subline. Controlled pollination achieves a union of desirable gametes which may not take place in uncontrolled conditions (Hand and Matheson, 1983). The mating designs proposed for the second-generation parents (to produce the second-generation Population) in this Breeding Population vary between and within sublines. Details are given below. A flow-chart showing the proposed timing and sequence of operations in Sublines 1 to 5 of this Breeding Population is given in Fig. 1.

Sublines 1 to 4. The main mating pattern proposed in each of these sublines is an incomplete polycross (a form of nested polycross - Burdon and Shelbourne, 1971). As far as possible, the best 15 of the 30 parent clones will be used as female parents, and the other 15 as males in a pollen mix. The main reason for using this design in these sublines is to provide general combining ability (GCA) estimates of clones as a basis for culling Windamere Seed Orchard. Therefore, as many as possible of the clones represented in this orchard will also be included in the group of 15 females.
FIGURE 1. Flow chart showing the idealised development of Sublines 1 to 5 of the "Granite/Sedimentary" Breeding Population.
The polycross mating design is operationally simple, involving only 15 crosses per 30-parent subline. High levels of genetic gain are possible from the incomplete polycross, especially if used in conjunction with efficient selection strategies such as combined index selection (as proposed - see later discussion). More elaborate mating designs, such as the disconnected half diallel, would theoretically give larger gains in the Breeding Population, for example, 0.95 phenotypic standard deviations (SD's) of the trait being improved, compared with 0.71 SD's per generation for the polycross, at an individual heritability of 0.2 (Cotterill, 1986). However, these elaborate designs would take far longer to achieve and, as the main design for these sublines, would be beyond our resources.

The polycross design has an important advantage in this case of providing estimates of GCA and breeding values for those second-generation parents used as females which are also in Windamere Seed orchard. Clones of poor GCA can then be culled from the orchard. Information on the GCA's of female parents will also be valuable for identifying outstanding parents for used in control-pollinated (c.p.) seed orchards, a strategy considered promising by Carson (1986) and Burdon (1986).

On the other hand, polycross mating has disadvantages as a means for producing the next generation of the Breeding Population, because of the high consanguinity (relatedness) among the offspring within a subline, possibly increasing the rate of inbreeding (Shelbourne et al., 1986). The number of existing seed orchard clones actually to be included in these four sublines has not yet been finalised. If a sizeable majority of these clones are not included, polycross mating will not be used for Sublines 1 to 4. Instead, these 120 selections will be crossed using single-pair mating (SPM), as proposed for the other sublines (see below).

General combining ability estimates will still be required for the seed orchard clones, however. These will be provided if necessary by a separate polycross mating scheme, using a standard pollen mix of about 20 males (see later discussion).

The four or five clones included in each subline as being specifically adapted to each of the 'granite' and 'sedimentary' site types will be crossed using a half-diallel mating design, additional to the polycross or SPM (which includes these clones). This means, for example, that the five 'granite' clones will be crossed to give 10 full-sib families, with each parent represented in four of these families; the same operation will be done with the 'sedimentary' clones. This relatively small number of supplementary crosses between high-quality parent clones gives a greater chance of generating outstanding full-sib families within the Breeding Population (since each clone will be crossed with several others), which could also be reproduced in c.p. seed orchards.

This approach is analogous to the 'top diallel' proposed under the New Zealand FRI Breeding Plan, where the six top parents of the 60 per subline are crossed in a half-diallel, in addition to pair-crossing among all parents (Johnson and King, 1988). This supplementary crossing is expected to give superior gains per generation in the New Zealand breeding population. In our case it will in effect create a small 'nucleus population' (Cotterill, 1984) of elite full-sib families for each of the granite and sedimentary site types. Subsequent testing of these families (see later discussion) may show some to be generally-adapted and others adapted to either major site type. Through the use of c.p. seed orchards, the most promising crosses could be used to contribute planting stock for the most appropriate site type.
The 120 parent selections used to produce the second-generation Breeding Population will be mated in the Breeding Arboretum at Tumut or in clone banks (depending where established ramets are located). The aim, in these and other proposed sublines, will be to produce at least 500 viable seeds per cross, requiring about 20 female flowers for each cross. This amount of seed should be sufficient to establish the second-generation Population over several sites and to keep a reserve of seed for exchange with other breeders, and enable production of cuttings of superior full-sib families.

In each of these sublines there will be a maximum of 35 crosses to achieve (15 polycrosses and up to 20 in the diallels), or 140 crosses over the four sublines. This represents 2800 female flowers to pollinate, or about 2.5 seasons' work. This workload is considered to be achievable, provided the operation is well-managed. It may be reduced through co-operation with other organisations such as the STBA in South Australia, which is using many of the same families in its breeding programme. The STBA may be able to produce enough seed of some crosses for both its own use and the F.C.N.S.W.

Subline 5. Clones in this subline (28 New Zealand 268-Series and 875-Series clones) will be crossed using a single-pair mating design, to give 14 full-sib families. As these clones have not been tested in N.S.W., there will be no supplementary crosses in this subline. The single-pair (SPM) mating design has the great advantage (like the incomplete polycross) of minimising the workload of controlled pollination and is therefore relatively inexpensive. The SPM design does not provide estimates of GCA, but these are not needed for orchard culling, as none of these clones is included in N.S.W. seed orchards.

Cotterill (1986) has calculated that theoretical gains per generation in breeding populations (at an individual heritability of 0.2) from using SPM with combined index selection, will only be about 8% lower than those expected from the more elaborate half-diallel design with combined index selection, and considerably greater (by 22%) than gains from polycross mating with combined index selection. If gain per year is considered, the SPM design is superior to the diallel, and will give about 23% more gain than the polycross.

Crosses in this subline will be made in Lochinvar Clone Bank, since the clones are well-established there. Only about 280 flowers (14 x 20) will need to be pollinated - about two weeks' work.

Sublines 6 to 7. A single-pair mating design will be used for these sublines of South Australian selections. Many of the crosses may be done co-operatively with the STBA, possibly reducing the workload by half. No supplementary crosses are required, so a maximum of 30 full-sib families will need to be produced - about 600 flowers, or half a season's work.

Sublines 8 to 10 (or 8 to 11). A single-pair mating design is also proposed for these sublines of N.S.W. selections, as there is no need for GCA estimates to cull orchards. However, there may be selections from apparently interactive families, adapted to granite or sedimentary sites, included in each of these sublines. All 30 clones per subline will be crossed in single pairs (15 crosses per subline). The five (say) 'granite' and five 'sedimentary' clones will be crossed using a half-diallel design, as for Sublines 1 to 5, to contribute to a 'nucleus' population, as described earlier.

In each subline, a maximum of 35 crosses will be made, or a total of 105 (three sublines) or 140 (four sublines). This represents 2100 to 2800 flowers to be pollinated, which would require about two pollination seasons to complete. Pollinations will be carried out in Tumut Breeding Arboretum when second-generation clones are well established.
The Breeding Strategy for Radiata Pine in New South Wales Part II - Proposed Operations

Sublines of Californian selections (Sublines 11 to 13 or 12 to 14). A similar SPM mating design to that proposed for Sublines 5 to 10 will be used for the 30 selections in each of these sublines. The number of crosses required in the three sublines would total 45 (900 flowers), less than one year's work in Tumut Breeding Arboretum.

The pairing of parents for mating in those sublines where the SPM mating design is used will not be at random. Instead, selections from families with complementary characteristics will be paired as far as possible (complementary or corrective mating, described by Cotterill, 1984). For example, selections from families with a high rank for diameter and a mediocre rank for stem straightness would be crossed with those of lower diameter rank, but superior stem straightness. This scheme is also proposed in the New Zealand breeding population (Johnson and King, 1988) and is used in a Florida slash pine (P. elliottii) co-operative breeding programme (Dr. T. White, University of Florida, pers. comm.).

Ideally, general combining ability (GCA) estimates should be obtained for all selections in the Breeding Population, to identify the very best to include in future seed orchards. This is proposed in New Zealand, where all selections will be crossed using a polycross design or a North Carolina II design, with five tester females (Shelbourne et al., 1986; Johnson and King, 1988). In our case, this would involve at least an extra 30 crosses per subline, above those proposed to create the new generation (e.g. one polycross family per selection), which is a large extra workload in total, but achievable if spread over several years.

(v) Selection for the third-generation breeding population. The polycrossed and full-sib families generated by the mating in each subline will be planted out in the field for the purpose of regenerating the Breeding Population, by forwards selection of third-generation parent clones from superior families. The potential gains in the Breeding Population from the use of forwards selection as parents for the next generation are considered to be substantially greater than those from using previous-generation female parents of (now) proven GCA (backwards selections), because the forwards selections are more advanced genetically (Dr. P.P. Cotterill, C.S.I.R.O. D.F.R., pers. comm.). GCA estimates will not be available for most of the second-generation parent clones in this Breeding Population (those crossed in single-pairs), and thus forwards selection is the only option in most sublines.

Special extra crossing programmes would be necessary to test for GCA's of parent clones in each generation of the Breeding Population (discussed previously). This is relevant only to backwards selection for seed orchards, especially control-pollinated orchards relying on GCA estimates to mate the best parents.

The outplantings of the second-generation Breeding Population will be established over four sites, carefully chosen for security from fire and other damage, and representative of the site types on which plantations derived from this Population will be grown. Two granite/granodiorite and two sedimentary sites will be used.

At each site, the sublines in the Breeding Population will be planted in the same randomised design. For example, up to 154 control-pollinated families in Sublines 1 to 5 will be randomised together in the same field layout at each site. The segregation of individual selections into different sublines only needs to be done on paper, when controlled crossing is planned. Due to the variable times of selection of the second-generation parents, different groups of sublines will be planted out at different times (e.g. Sublines 1 to 5 together, Sublines 6 and 7 together, and Sublines 8 to 10 or 11 together, later).
About 50 offspring per family will be planted at each site (200 per family across the four sites). In addition, currently available N.S.W. seed orchard seedlots will be planted as controls, as well as Standard Research Working Group 1 (RWG1) seedlots (Griffin, 1978). The proposed field layout at each site will be randomised complete blocks, with 3- or 4-tree row plots. These are a compromise between small plot sizes of one or two trees recommended by Cotterill and James (1984) as being most efficient for comparing families, and the potential of large plots to allow more efficient selection within families. The row plots will be much simpler to establish without errors in the field. The planting espacement will be 3.0 x 3.0 metres.

Because a very large total number of trees (about 30 000 over Sublines 1 to 5 alone) will be established in these outplantings, the workload of assessing them all for several traits would be enormous. A two-stage assessment is proposed, whereby all trees will be measured for diameter at age five to six years, for the purpose of ranking families within sublines. Only the top-ranking 60% of families per subline will then be finally assessed, for diameter, stem straightness, branch quality and number of whorls of branches, and possibly wood BD, at age eight to ten years (a total of about 18 000 trees).

Selection of third-generation parent clones will be carried out using a combined selection index (RES13 - Cotterill et al., 1988; or a later version of RES1, if available), which integrates individual and family information on assessed traits for individual trees. Cotterill (1986) has shown that this selection method is expected to produce maximum genetic gains in the Breeding Population per unit time, when used in combination with either the single-pair of polycross mating design. Combined index values will be calculated for all offspring finally assessed in each subline, and the best 30 individuals selected as third-generation parents (including possibly some from 'interactive' families, to continue the specialised nucleus population, as described earlier).

The main problem with combined index selection is that rates of increase of inbreeding within sublines can be much greater than under other selection methods, because of the potentially strong component of family selection involved. This rate of increase may be reduced in practice by setting a limit on the number of individuals selected from any one family. Cotterill (1986) recommends a limit of five per family, entailing the risk of a small loss of genetic gain in the breeding population. A more conservative restriction of three selections per full-sib family will be applied under combined index selection in this Breeding Population. This will allow mainly within-family selection to be used, with less emphasis on between-family selection, in the Breeding Population, which is considered the better selection strategy to help control inbreeding in sublines (Shelbourne et al., 1986).

Theoretical calculations of expected rates of inbreeding incurred by using the preferred option of single-pair mating with combined index selection in the third generation of all of these sublines will be made early in the period of the Strategy. If inbreeding is considered to be developing too rapidly, a different mating design may be adopted for the third-general parents (e.g. double-pair mating) to slow its onset. This would involve a trade-off between reducing the rate of inbreeding in sublines and the increased workload entailed in a necessarily more elaborate mating design.

The generation interval, from the time the second-generation clones are all selected, to the same stage of development of the third-generation selections, will be about 14 years (1989 to 2003), if all operations are carried out efficiently and on time.
(b) Breeding Population for *Dothistroma*-affected sites, and Basalt and Metabasic Site Types (*Dothistroma*-resistant Breeding Population)

(i) Description of site type. This Breeding Population will serve a dual role. It will be used as the source of plantation stock for all areas frequently susceptible to *Dothistroma* needle blight, over all geological types. The majority of these areas are on the Northern Tablelands of N.S.W. (Glen Innes Region), where most plantations are at risk. Genotypes developed in this Population will also be utilised in plantations on ferromagnesian (basic) parent materials - basalts and gabbros (Level 1 parent rock Code 111 - Turvey, 1987) in Glen Innes and Bathurst (mainly Canobolas and Glenwood S.F., Orange District) Regions. A considerable area of the *Dothistroma*-susceptible plantation already established on the Northern Tablelands is also on basic geological types (with small areas on sediments and granites). As mentioned earlier, significant areas of plantation in Albury Region on basic geology mixed with other rock types will probably be planted with genotypes produced in the Granite/Sedimentary Breeding Population.

Overall, basic parent material sites occupy about 10% of the current N.S.W. plantation area (excluding Albury Region). Significant areas of land purchased for future plantations in Glen Innes Region will also be of this geology. Even larger areas of purchased country here will probably be on sediments. All purchased areas are expected to be favourable for the development of *Dothistroma* infection.

Soils on the basic parent materials are generally very fertile, and radiata pine grows quickly, but the trees often suffer from sulphur (S) and boron (B) deficiency, associated with an over-abundance of nitrogen (N), leading to leader death, malformation of stems and thick branches. S-deficiency is also implicated in susceptibility to *Dothistroma* (Lambert, 1985), which is difficult to control by spraying.

(ii) Selection for the second-generation breeding population. The second-generation Breeding Population will initially be composed of 93 selections from five progeny tests established in Albury and Glen Innes Regions from 1966 to 1973, and which received a final assessment by 1985. These second-generation clones represent 82 unrelated families and 90 unrelated first-generation parent selections (see Table 2). Four of the five tests are on basalt geology (Nundle S.F.), and have been subject to *Dothistroma* infection. The fifth test (Q14111, in Wee Jasper S.F.) is on metabasic parent material, but not subject to the disease. However, it is proposed that a small number (11) of selections will be taken from this test, since it is on definitely basic rock types and it is a source of several high-quality N.S.W. control-pollinated families for growth and form, which are required to help bring the ultimate number of unrelated second-generation selections in this Population closer to the goal of 200. The 28 New Zealand clones, as used in the Granite/Sedimentary Breeding Population and described earlier, will also be included.

Further second-generation selections will be taken from Progeny Test Q14607, on a basalt site at Nundle S.F. After the final assessment of this test (about 1996), about 45 selections will be taken from the 125 open-pollinated families in the test, selected by index on the basis of growth and form traits, as well as *Dothistroma* resistance and wood basic density (BD).

This will give a total of about 160 unrelated second-generation clones in this Population. This number may be boosted in the longer term by the progeny testing of a further 50 first-generation plus trees, previously selected in Nundle S.F., over the next few years.
Table 2. Families proposed to be represented by second-generation selections in the initial *Dothistroma*-resistant Breeding Population.

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268 - families are New Zealand selections, to be represented by 2-generation selections of the N.Z. 875 clonal series

* = original first-generation selection
The 90 unrelated first-generation parents to be represented initially by second-generation clones in this Breeding Population therefore represent a family selection intensity of slightly less than 1:3 (90/252). A similar selection intensity (45/125) will be applied to the 1987 progeny test.

(iii) Structure and mating pattern in the second-generation breeding population. Genotypes produced in this Population are to be used over a much smaller plantation area than those from the Granite/Sedimentary Breeding Population. Given this fact, and the limited resources available to implement the Breeding Strategy as a whole, it is proposed to use a simple mating design and selection strategy in this Population. Another reason for the relatively low key approach in managing this Population is that other, special efforts will probably also be devoted to developing *Dothistroma*-resistant genotypes adapted to sites with low S and B (see Section on Production Population).

The Population at present contains 121 second-generation parent clones, including the 28 New Zealand 268-Series and 875-Series clones. This number is not expected to increase for several years. The selections available are considered sufficient to set up a viable Breeding Population in the near future, and this can be enriched with further selections in the third generation. A flow chart showing the proposed sequence and timing of operations in this Breeding Population is given in Fig. 2.

An open-pollinated mating design will be used. This design is operationally very simple, requiring no controlled pollinations. The labour saved thereby will be used to establish more offspring in the Breeding Population, permitting more intensive selection within-families in the third generation. Under this mating design, sublining of the Population would entail planting out each subline on a site isolated from others, to avoid cross-pollination (Cotterill, 1986). This is not possible logistically in the present case.

The Breeding Population will therefore be developed as a single large population, even though this implies less control over inbreeding and probably lower genetic gains than would be achievable in a sublined population. Crossing among the parents will occur in a clonal planting adjacent to Walcha Seed Orchard, Glen Innes Region. The 121 parent clones will be planted out as grafted ramets in a stand beside the Orchard, so that pollen from both the stand itself and the 60 clones in the Orchard will fertilise flowers on the parent clones. Each parent will be represented by six or eight ramets, at a spacing of 4 metres x 4 metres (a total of up to 970 ramets, covering about 1.6 ha.). The pollen cloud should come from most or all of the 121 clones, and be of high genetic quality.

Cones will be collected from each clone when the pollen cloud is considered to be representative of the 121 clones. This may be up to seven or eight years after establishment of the clonal stand.

(iv) Selection for the third-generation breeding population. Selection of third-generation parents will be within-families, to minimise inbreeding in the Breeding Population. The second-generation Breeding Population, consisting of 121 open-pollinated progenies from seed collected in the clonal stand, will be planted out over two sites typical of plantation areas on basalt parent material, and susceptible to *Dothistroma* infection.

At each of these sites, two types of planting will be established:

1. A large family-block planting, with 100 trees per open-pollinated family in a single 10 x 10-tree block (12 100 trees per site), planted at 3.0 x 3.0 metres. Establishment of these blocks should be done carefully, so that tree-to-tree environmental variance is minimised (Burdon and Shelbourne, 1971).
FIGURE 2. Flow chart showing the idealised development of the *Dothistroma* - resistant Breeding Population.
2. A small progeny test, with 30 trees per open-pollinated family, in single-tree plots (a total of 3630 trees per site). This test will be assessed at age three or four years for *Dothistroma* infection, and at age eight years for growth and form traits and wood BD. These five traits will be integrated into a multi-trait selection index, to select second-generation parents of high GCA for the index, to include in new seed orchards. These new orchards are most likely to be control-pollinated. A between-family selection intensity of 1:6 or 1:7 will be applied.

The overall best tree per family will be selected phenotypically (without assessment) from one of the plantings or progeny tests, as a third-generation parent, to regenerate the Breeding Population. This selection will be on the basis of *Dothistroma* resistance, growth rate, form (including lack of malformations), and wood BD. A high within-family selection intensity of at least 1:200 will therefore be possible for each of these third-generation parents (forwards selections).

Scions will be collected from the 121 third-generation parent clones as soon as possible after selection, and a new clonal stand established, possibly in conjunction with a small new-generation open-pollinated seed orchard, established to augment the pollen cloud for the clonal stand. Extra new *Dothistroma*-resistant selections will be available by this stage from progeny Test Q14607, in Nundle S.F., and possibly from New Zealand, and will be added to the Breeding Population.

Implementation of this strategy for the *Dothistroma*-resistant Breeding Population will be relatively slow, with a generation interval of about 18 years, due to delays while waiting for pollen clouds to be produced in the clonal stands. Operationally, this is not a problem, as improved genotypes for this site type are expected to come on stream from established orchards while the second-generation Breeding Population is being developed. Third-generation parents in the Breeding Population, and tested second-generation clones for new seed orchards, will be available by the time the present orchards approach the end of their useful life, about 2008.

3. The Production Population

This Population is the top level of the hierarchy of populations. It consists of clones of the best few of the genotypes in the Breeding Populations, and is the Population that will produce seed and/or rooted cuttings for use in routine plantations.

Two types of Production Population are envisaged under this Strategy:

1. Best individuals from proven superior families, selected at a high intensity from Breeding Populations and propagated to seed orchards to produce improved seed (which may be multiplied by vegetative propagation of seedlings, to give rooted cuttings). These orchards may be managed as open-pollinated (o.p.) or control-pollinated (c.p.) orchards, or both - see later discussion.

2. Clones of proven outstanding control-pollinated families, or special purpose crosses between selected parent clones (from within or outside the formal Breeding Populations, as described in the previous Section), from which rooted cuttings stock will be mass-propagated.

These two types of Production Population will be used in combination to produce planting stock within the next few years. It is expected that by about 1995, the F.C.N.S.W. will be producing all its planting stock from genetically-improved sources.
(a) Present Production Population

(i) Clonal seed orchards. The present Production Population is based on four clonal seed orchards: Vulcan Seed Orchard (Bathurst Region), Tallaganda Seed Orchard (Bateman’s Bay Region), part of Windamere Seed Orchard (Dubbo Region) and part of Walcha Seed Orchard (Glen Innes Region). Vulcan is an old open-pollinated orchard, established between 1966 and 1972. Tallaganda was replanted between 1983 and 1987 on the same site as the original Tallaganda Orchard, while Windamere and Walcha are both still in the process of establishment.

**Vulcan Seed Orchard.** This Orchard has so far produced relatively poor seed yields over its productive life, averaging about 8 kg/ha/year, with a peak of 23 kg/ha in 1983. Very little seed has been produced there since 1986. The whole Orchard has been pollarded at a height of five to six metres, most of the area being treated between 1986 and 1988. Fertiliser was applied in spring 1988, and a response to this treatment and the pollarding is hoped to result in seed production of 800 to 1000 kg/year from early 1990’s (12 to 15 kg/ha/yr).

This Orchard will need to be retained for several more years, at least until Windamere Seed Orchard becomes fully productive (around 1995), and probably beyond, if the genetic quality of the seed produced proves to be consistently superior to unimproved alternatives. Preliminary results (age six years) from progeny tests in which bulk Vulcan Orchard seed progeny is included, indicate gains in conic volume by Orchard seed over clearfelling seedlots averaging 28%, over several different sites (11 out of 12 of the available percentage gain figures were positive for the Seed Orchard seed).

**Tallaganda Seed Orchard.** Most (3.9 ha) of the original Tallaganda Seed Orchard (Queanbeyan District) has bee re-established as a ‘specialist’ o.p. orchard, to provide seed of *Dothistroma*-resistant clones suitable for establishing plantations on high-hazard sites such as areas in the Northern Tablelands of N.S.W. Stock produced from this orchard can be expected to have genetic resistance to *Dothistroma* (Wilcox, 1982).

Re-establishment was completed in 1987, with significant seed yields expected from about 1994. This orchard site was very productive of seed in the past; yields of up to 75 kg per year can probably be expected from this small area by 1997.

**Windamere Seed Orchard.** This Orchard, in Mudgee District, is presently 40 ha in area, and expected to reach about 50 ha later in 1989. The layout design used assumes o.p. management. The whole orchard will be irrigated. Establishment was commenced in 1985 (seven ha), using grafted ramets of 24 progeny-tested first-generation (or 1.5-generation) and second-generation clones, with greater numbers of ramets of clones of the higher general combining ability (GCA) families. Dr. A.C. Matheson of C.S.I.R.O. D.F.R. provided assistance with the design.

Areas planted in 1986-1988, and the proposed 1989 age class, employ a randomised block design. In 1986, 14.2 ha net were established, using grafted ramets of 25 clones from families of proven superiority over a range of sites. In early 1987, it was decided to develop this Orchard as a source of seed for plantations on sediments, and therefore to use clones from superior families selected on this geological type. The 36 clones in the 1987 age class (3.8 ha net) were all selected in Gurnang S.F. (Oberon District), and are all different from the 1986 age class clones.
The 1988 age class (12.5 ha net) utilised 30 clones, including several used in 1986 from families superior on sedimentary sites, as well as other 'sedimentary' selections not previously used. The 1989 plantings will be of the 1988 clonal mix.

Walcha Seed Orchard. This new seed orchard is currently 7.7 hectares in area, established in 1987-1988, using grafted ramets of 48 (1987) and 60 (1988) second-generation clones selected in two progeny tests in Nundle S.F. (Tamworth District). The parent clones were selected in families displaying superior growth, health and form, implying resistance to Dothistroma. Eleven (11) of these clones have also been used in Tallaganda Orchard. The layout is randomised complete blocks. The ultimate area is expected to be 9 to 10 ha. Irrigation will be supplied to the Orchard in the near future.

(ii) Imported seed orchard seed. The current seed requirement of the F.C.N.S.W., for its own use and private sales, is about 1300 kg per annum, with all areas of plantation being established using seedlings. Almost no seed has been available from N.S.W. seed orchards over the past two or three years. About 21% (263 kg) of this shortfall was made up in 1988 with seed orchard seed purchased from Proseed (New Zealand). This seed, with Improvement Ratings of GF 14 and GF 16 (N.Z. F.R.I., 1987), includes several clones of New Zealand 850-Series (whose progenies have performed very well in International Gene Pool Trials in New South Wales) and 268-Series, and can be expected to give plantations of superior growth and form to those derived from unimproved seed sources (see also Section on Demonstration Plantings).

(iii) Present sources of unimproved seed. A large proportion of the seed used to produce planting stock in recent years has come from final fellings in pre-war and early post-war stands. Seed from this operation is derived from about the best 100 trees per hectare, a selection intensity of about one tree in 15. This is low-intensity mass selection in first-generation stands, and can be expected to result in genetic gains of only about 3% for diameter and 12% for stem form, compared with seedlots collected from a random sample of trees in unthinned first-generation stands on similar sites (following calculations of Shelbourne, 1969). Available results of trials comparing clonal seed orchard seed with clear-felling seedlots in N.S.W. support this contention, and indicate a general superiority of the seed orchard seedlots (Green Hills, Tallaganda and Vulcan). Gains by these seedlots for volume at six to eight years averaged 22%, over several sites, with the Tallaganda and Vulcan seedlots mostly performing better than those from Green Hills Seed Orchard.

(b) Future Seed Orchard Production Populations

Clonal seed orchards may be managed using two basic pollination systems - open-pollination (o.p.) and controlled pollination (c.p.). A brief discussion of these options is relevant at this point in the paper.

Conventional o.p. seed orchards, as widely used in 1960's and 1970's, have proved a reasonably successful but cumbersome method of improved seed production (Burdon, 1986). The main problems, are: the long lead time from selection of clones to full seed production; contamination by outside pollen; difficulty of applying cultural treatments or assisted pollination on an individual clone basis; impossibility of adding superior new clones to an orchard as they are selected in the breeding population. The long period (20 to 25 years) that these orchards need to be in place to be productive and economical means that seed produced is often out of date in genetic quality relative to that potentially available from new selections.
To obtain the greatest benefit from improved genotypes via a seed production population, seed orchard managers need to be able to exercise control at all stages from flower induction to seed development. The use of c.p. orchards considerably reduces lead times until seed production; it gives flexibility in modifying the suite of clones so that the best crosses can be produced as information becomes available; clonal plantings are consolidated for ease of specific management treatments clone-by-clone; new improved clones can be added at any time, to be productive within three to four years (Griffin, 1988).

Control-pollinated orchards range from conventionally laid-out o.p. orchards, hedged and mass-pollinated with a pollen mix for a few years, to specially laid-out orchards with hedged rows of particular clones (e.g. Hedged Artificially-pollinated Seed Orchards (HAPSO's) in Western Australia - Butcher, 1988), to which selected pollens are applied. A fuller description of options for management is given later. Such seed orchards are becoming widely recognised in Australasia as the most efficient means of mass-producing highly selected genotypes by seed, although there are technical problems still to be solved.

The F.C.N.S.W. will plan to manage any seed orchards established in the 1990's and later as control-pollinated orchards, guided by the experience of other organisations using these systems.

(i) Requirement for new clonal seed orchards. Clonal seed orchards are expected to be the mainstay for providing genetically improved planting stock in New South Wales for many years to come. There is an urgent need to maximise yields from existing orchards, as described above, and to establish further orchards to ultimately replace Vulcan Seed Orchard, aiming to produce at least 1300 kg of seed (or the equivalent number of planting stock as seedlings and cuttings) per year overall.

It is imperative to have orchards in production on at least two or three sites at any one time, as insurance against calamities such as wildfire. The Ash Wednesday fires in South Australia and Victoria in 1983, when several seed orchards were destroyed, provided an object lesson in this regard. Under a multiple-population strategy, as currently proposed for N.S.W., meeting this ideal would theoretically entail maintaining up to six orchards at any one time, catering for the three different ‘site types’ (as defined previously). This number of sites could be reduced by, for example, establishing a ‘granodiorite’ and a ‘sedimentary’ orchard adjacent to each other on each of two large sites, instead of having four separate smaller orchards, an approach which would be more efficient in terms of management.

Projected requirements for new seed orchards are discussed briefly below, by target site types:

Granite/granodiorite sites. A planting stock requirement equivalent to about 550 kg of seed per year is assumed. At present, there is no orchard in existence specifically designed to provide seed for this site type. Seed from some of the clones in Vulcan Orchard will be used for granodiorite and mixed granodiorite/basic rock sites in Albury Region, once the orchard becomes productive again. Seed of clones which appear to be better adapted to sedimentary sites should not be used on the ‘granite’ sites. Continuing use of seed from Vulcan Orchard will, however, be based on its achieving substantial realised gains over competitively-priced alternatives over a range of sites. Seed from some of the clones in Windamere Orchard will probably be found to be suitable (once the GCA’s of the clones are known) for ‘granodiorite’ as well as ‘sedimentary’ site plantations, and thus some of the seed required for the granite sites could be supplied from Windamere Orchard.
At all events, new areas of seed orchard will probably need to be established to cater for the 'granite' sites, aiming to replace Vulcan Orchard soon after the turn of the century. Control-pollinated orchards are proposed, to be planted in the early 2000's on sites selected for high seed yields. A relatively small area of about 10 to 15 ha would be required, in two geographically separated sections for security. Second-generation clones of proven high GCA would be available for such orchards by then (see section on culling of seed orchards, below).

**Sedimentary sites.** About 600 kg of seed or equivalent is required for plantations over the more fertile sedimentary sites, as well as low-phosphorus and acid volcanic sites. Windamere Seed Orchard is expected to be the main source of this seed, once it becomes fully productive (by about 1995, if left to develop as an o.p. orchard). In the interim, some of the clones in Vulcan Seed Orchard (those whose progenies appear well-adapted to sedimentary sites) are expected to provide up to half of the seed requirement.

The immediate need for further seed orchard area for these site types will be met by the planned expansion of Windamere to 50 ha. The full orchard can be expected to yield at least 800 kg of seed per year (under o.p. management), thus more than adequately catering for the sedimentary sites. This orchard has disadvantages in terms of security, being in one large single block. This is unavoidable, since the establishment is virtually fait accompli, and it will necessitate special efforts in protection.

Establishment of further seed orchards to cater for granodiorite and sedimentary sites will be necessary by about 2005, to enable Windamere Orchard to be phased out (about 2010 to 2013).

**Dothistroma-susceptible and Basalt sites.** Adequate o.p. seed orchard area will be established by 1989, at Tallaganda and Walcha, to cater for the Northern Tablelands sites and Bathurst Region basalt sites. The two orchards between them (about 12 ha) can be expected to yield at least 150-180 kg of seed per year after about 1995, which will be more than enough to supply these sites. The orchards are separated geographically, so there would be little risk of losing both of them. No requirement for further seed orchard area to supply these site types is envisaged until about 2010, when the existing orchards will be phased out.

The total area of new seed orchards required for all site types in this later period will depend on several factors, such as the amount of seed being used per year by then (this could be relatively small if seedling stock is augmented by mass vegetative propagation), and the effectiveness of management techniques in boosting seed production per area of orchard. If c.p. orchards are in wide use, large amounts of seed could be produced over small areas.

(ii) **Clones for future seed orchards.** A general policy is proposed of using the most advanced genetic material available. This has been done in the recently-established orchards (since 1984), in which the clones are almost all second-generation (forwards) selections from progeny tests. Future seed orchards here includes both those to be newly established, and those already established but which are proposed to be culled (rogued) to fewer clones to improve potential genetic gains. Culling of existing orchards is discussed first, below:

**Windamere Seed Orchard.** Clones in this orchard were selected from families of high mean performance, and consequently relatively few were established (between 24 and 36, depending on age class). This clonal composition gives latitude for only a light culling on the basis of GCA and seed yields of clones, and possibly their health. However, it is still considered advantageous to cull the 1986 to 1989 age classes down to a level of about 15 to 18 excellent clones. The South Australian Breeding Plan (Cotterill,
The Breeding Strategy for Radiata Pine in New South Wales Part II - Proposed Operations

1984) specifies a minimum of 20 clones for advanced-generation orchards, while Dr. D. Lindgren, Swedish Uni. of Agricultural Sciences, Umea, (pers. comm.) recommends 12 to 15 as an optimal number of clones, and possibly slightly more, in radiata pine orchards.

Testing of the progenies of all the Windamere clones should be carried out, to give estimates of GCA's over a range of sites. This information will indicate which clones are suitable for granite sites, sedimentary sites, or both, and indicate clones of outstanding GCA with potential for controlled crossing and mass vegetative propagation (discussed later, under Cuttings-based Production Populations). Culling of low-GCA clones from the orchard can be expected to raise expected gains from the use of bulk seed, although these extra gains may be small due to the low intensity of culling that would be possible (1:3 at maximum).

The GCA's of most of these clones may be estimated from the outplantings of the first four sublines of the Breeding Population, by about 2000 (if polycross mating is used), allowing culling at 12 to 13 years old, so little extra progeny-testing work would be required in this case. Otherwise, a special crossing programme outside that proposed for regenerating the Breeding Population would be necessary to estimate GCA's of these clones.

**Tallaganda Seed Orchard.** This orchard contains 30 second-generation clones selected from families in Nundle S.F. which show apparent resistance to *Dothistroma*, but the clones have not yet been screened for GCA for resistance (or any other traits). This needs to be done as soon as possible, to enable the Orchard to be culled down to about 15 clones, also incorporating information on seed yields and clonal health.

Polycrossed (control-pollinated with a mix of pollens from all or most of the clones in the orchard) seed from most of all clones should be able to be produced in Lochinvar Clone Bank by 1992, and these polycross families tested for resistance, growth and form in small progeny tests over two or three sites, by 1998. The GCA information gained will be used to cull out the poorest clones, for resistance particularly, when the Orchard is 13 to 14 years old.

**Walcha Seed Orchard.** This Orchard was designed to be culled heavily, and contains 48 (1987 age class) and 60 (1988 age class) clones. As in the case of Tallaganda Orchard, culling on the basis of GCA for *Dothistroma* resistance, growth and form is planned, to retain 15 to 18 clones (a culling intensity of 1:3 to 1:4). This culling is expected to give substantial increases in genetic gain from bulk seed, as well as indicating individual clones of especially high GCA.

Testing for GCA will employ polycrossed seed of as many of the orchard clones as possible. Ramets bearing female flowers should be available in Lochinvar Clone Bank by 1992, allowing pollination in that year and field testing of the polycross families in two or three small progeny tests from 1994 to 2000. Culling can then take place when the Orchard is 10 to 12 years old. This is considered to be the most important of the already established Orchards to cull; if labour is limited, the procedures outlined above should be given priority over similar operations in Tallaganda Seed Orchard.

The composition of clonal seed orchards still to be established after the early 1990's, and proposals for culling them (where relevant), are discussed below:
New second-generation ‘granite’ seed orchards. If possible, new seed orchards will be established as c.p. orchards, using second-generation clones of proven high GCA. Outplantings of Sublines 1 to 4 of the Granite/Sedimentary Breeding Population may yield the GCA estimates for about 60 second-generation clones (if polycross mating is used), by about 2000, allowing the few very best clones for granite sites (e.g. 10 to 15, or three to four per subline) to be included in the new orchards. This would mean delaying establishment several years compared with o.p. orchard option. However, this may be an advantage in that technology for c.p. seed orchard management should be well developed and current problems solved by then.

New third-generation orchards for granite and sedimentary sites. Third-generation selections will be available from the Granite/Sedimentary Breeding Population by about 2004, that is, soon after the high-GCA second-generation clones are identified. The very best forwards (third-generation) selections could be used for c.p. orchards to produce seed for either or both site types, before testing them for GCA. Calculations in New Zealand suggest that pair-mating and forwards selections will give more gain on average in c.p. orchards than backwards selection on GCA (Dr. G. R. Johnson, New Zealand FRI, pers. comm.). This means that superior (GCA-tested) second-generation clones (‘backwards selections’) and third-generation clones (‘forwards selections’) could be used for seed production simultaneously or within a few years. Two or three clones per subline would be used, with no need for culling. All crossing in c.p. seed orchards will be between clones from different sublines, to avoid inbreeding in the Production Population. Superior specific crosses from among the supplementary diallel crosses in some sublines could also be reproduced in these orchards.

New third-generation orchards for Dothistroma-susceptible sites. Control-pollinated seed orchards over two sites are proposed after the two existing seed orchards (Tallaganda and Walcha) are discontinued (about 2005-2010). About 10 to 15 clones of proven high GCA for growth, form and Dothistroma-resistance will be crossed in these orchards. These could include the best of the clones retained in Walcha Orchard after culling, other second-generation parent clones of high GCA identified from progeny tests in the Breeding Population, and possibly some superior Dothistroma-resistant clones from the New Zealand breeding programme, obtained by co-operative exchange with the New Zealand FRI. Seed from these orchards may be supplemented by cuttings produced from other special crosses between resistant clones, as proposed in the Clonal Production Population (see Section on Cuttings-based Production Population).

(iii) Design of future clonal seed orchards. New o.p. seed orchards (if any) established after 1990 would contain many clones initially, with culling intensities of about 1:4 applied among the clones. Therefore, a relatively large number of ramets would be established per hectare (about 290, at a 7.5 x 4.5 metre spacing). This fairly close spacing would aid in the early development of effective pollen clouds in the orchards. Control-pollinated orchards are the preferred option. These would be established using a larger numbers of ramets per hectare. In the Western Australian HAPSO’s, spacings of 6.0 m. between clonal rows and 2-3m. within rows are used (560 to 830 ramets ha-1). A ‘box row’ layout has also been proposed (Butcher, 1988), with double hedges per clone, and 6.0 metres between these, giving 1250 ramets per ha. Close spacing within the rows of clones used as female parents is employed to restrict the surface area available for the development of unwanted pollen.
Proposed seed orchards (either o.p. or c.p.) will be established using grafted ramets, since facilities for grafting are already well established and problems of graft incompatibility should be reduced by intensive management of all seed orchards (fertiliser and irrigation, particularly), and a quick clonal turnover, in c.p. orchards. Rooted cuttings are another option, but using cuttings from advanced-generation ortets older than about four or five years from seed is not practicable, due to the difficulty of getting physiologically-mature cuttings material to form roots. Scions for grafting will be taken from parent ortets as soon as possible after selection, or from ramets in clonal archives (clone banks or breeding arboreta), depending on whether the seed orchard clones are forwards or backwards selections.

(iv) Siting of clonal seed orchards in N.S.W. The basic function of a seed orchard is to take selected genotypes produced in the breeding population, greatly increase their numbers, and package them in seeds to be used in plantations (Libby, 1973). The most carefully-managed breeding populations, promising great gains, will be wasted if the highly-improved genotypes produced from them are prevented from carrying out this ‘packaging’ procedure efficiently, through poor siting and/or management of clonal seed orchards. The importance of optimum siting and management of seed orchards cannot be overstated.

Basic requirements of site for any clonal seed orchard are that it should guarantee survival of a high percentage of the ramets, stimulate sexual precocity and support continued, abundant seed production. The environmental factors associated with regular and abundant cone production in radiata pine are not yet well understood. However, experience gained by seed orchard managers in Australia over 25 years suggests that orchards in coastal sites are generally more productive than those situated inland. Mean seed production from three low-altitude coastal o.p. orchards in Victoria and South Australia (Golden Gully, Mount Schank and Saxton’s), at ages 7 to 13 years from establishment, ranged from 17.4 to 27.7 kg/ha/year (Pederick and Brown, 1976), similar to yields from the original Tallaganda Orchard, but much higher than those from Vulcan or Green Hills Orchards (high-altitude, inland sites).

In summary, sites for any type of seed orchard should be selected which have the following characteristics:

- Mild climate, without extremes of heat or cold (especially frost).
- Freedom from frequent drought stress (this may be ameliorated by irrigation).
- Fertile soil, free from serious nutrient imbalances, which may prejudice the vigour of ramets or cone production.
- Isolation from sources of ‘foreign’ pollen - if large amounts of pollen come from outside the orchard, genetic gains may be reduced by as much as 50%.
- Flat or gentle topography, allowing easy access by machinery to all areas of the orchard.
- Fairly easy access by personnel involved in management and cone collecting operations. This is perhaps less important than the other five criteria above, for o.p. orchards, but is important for the more intensively-managed c.p. orchards.
(v) **Management of clonal seed orchards.** Management involves all operations necessary to keep an established orchard growing vigourously and producing the maximum possible amount of seed of a high genetic quality, as well as efficient collection of seed crops. Management plans will be produced for all new N.S.W. seed orchards, from Tallaganda onwards, to guide local orchard managers.

**Optimising yields and genetic quality of seed.** As outlined previously, there is a basic choice in seed orchard management systems involving control of female flowering and pollen, between open (o.p.) and controlled-pollination (c.p.), to improve the yield and genetic quality of seed.

The traditional open-pollination system used by clonal seed orchard managers is relatively cheap, in that management only needs to concentrate mainly on maintaining ramets in a state of vigour. The clonal composition of such orchards can be manipulated to a limited degree by culling inferior clones, as proposed for existing o.p. orchards in N.S.W., thus raising (generally slightly) the genetic quality of the bulk seed.

There is scope for increasing cone yields by crown manipulation in o.p. orchards through pollarding (topping). Matheson and Wilcock (1976) recorded a large increase in seed yield from blocks of Tallaganda Seed Orchard pollarded at eight metres at age 12 years. The response to pollarding may vary from site to site and clone to clone, so it would be wise to carry out an experimental-scale pollarding in orchards at about age nine to 10 years, to determine whether whole orchards should be treated. The speed of recovery of Vulcan Seed Orchard from its fairly severe pollarding in 1986–87, and its subsequent seed production, will also be a useful guide to the effects of pollarding at an advanced ramet age.

Another treatment that may be able to be applied in o.p. (and c.p.) orchards to increase female flowering, hence seed yields, is the application of gibberellic acids. There are numerous studies indicating the effectiveness of GA\textsubscript{3} and GA\textsubscript{4} in boosting yields in spruces and *Pinus sylvestris* in Europe (e.g. Luukkarinen, 1981; Chalupka, 1978; 1984). Much experimental work needs to be carried out with these hormonal treatments, however, before they could be recommended on a routine scale in radiata pine orchards. This subject is mentioned here mainly to highlight a potentially promising cultural technique worthy of practical investigation. Such treatments may be more relevant in c.p. orchards, where ramets are more accessible and grouped by clone.

Management of c.p. orchards allows close control over the genotype of seed produced, the ramets being hedged for easy access for pollination, and to stimulate female flowering. Some particular c.p. orchard designs in use at present are described briefly below.

The Southern Tree Breeding Association (STBA) in South Australia is control-pollinating ramets in the replanted Mount Schank Orchard (established as an o.p. orchard), using a pollen mix (Dr. D. Boomsma, South Australian Woods and Forests Dept., pers. comm.). Ramets are pollarded heavily from about age two years and flowers sprayed with a mix of pollens from available superior first-generation clones (supplementary mass pollination, or SMP). There is no isolation of flowers from background pollen. The aim is to keep ramets hedged at three metres for several years, but possibly allow them to grow and develop into tree form (and revert to open-pollination) later. Costs and yields relative to those associated with o.p. orchards have not yet been reported. The main benefit is seen to be early yields of seed of relatively high genetic quality, in three or four years compared with eight to 10 years under o.p. management.
In New Zealand, c.p. orchards are established using hedged rows of clones at a spacing of 5.0 x 4.0 metres (500/ha), with a pollen mix of selected males applied artificially. Female flowers are isolated by bagging to avoid pollen contamination. This isolation is expensive, seed from the orchards costing about six times as much as that from o.p. orchards. However, relatively small amounts of seed can be multiplied as juvenile cuttings, with expected multiplication rates of 8 to 20 (Shelbourne et al., 1986).

Hedged artificially-pollinated seed orchards (HAPSO's) have recently been established in Western Australia by the Dept. of Conservation and Land Management (Butcher, 1986; 1988). These consist of separate female and male orchards, established as low clonal hedges about two metres high. Production of specific superior crosses is possible. Control of the pollen produced on the female hedges is the major limitation to this type of orchard - selfing is likely if pollen develops on the female hedges. Emasculation of these hedges by application of maleic hydrazide is being tested in Western Australia (Tan and Butcher, 1988), and shows promise. It is expected that this type of treatment can be developed for routine use in c.p. orchards, thus reducing the need for expensive bagging of female flowers or the removal of pollen catkins by hand.

A novel concept of c.p. orchard management is being tested by Proseed New Zealand, based on the meadow orchard concept mooted by Sweet and Krugman (1977). Grafted ramets of superior, fecund clones were established in 1987 at a very close spacing (2 x 1 metres) on a site promoting very early abundant flowering. A selected pollen mix is to be applied to the dense stand of ramets for each of three years, after which the ramets will be replaced. Very large quantities of seed are expected to be produced over a few hectares of orchard (Wooff, 1988). This type of orchard management would accelerate by at least five years the rate at which superior full-sib families can be introduced into routine plantations. It also circumvents problems of pollen contamination, as ramets are used for pollination before they are old enough to produce much pollen.

Opportunities to manage the newly-established seed orchards in N.S.W. (Windamere, Tallaganda and Walcha) as mass-pollinated orchards, as the STBA is doing in South Australia, are limited, mainly because the infrastructure necessary to produce the large amounts of high-quality pollen necessary and to deliver it to thousands of ramets, has not been developed yet by the F.C.N.S.W. Further, there are as yet no data available on the relative gains and costs of such operations. Theoretical calculations for Windamere and Walcha Orchards indicate that potential genetic gains from applying SMP may be 1.2 to 1.3 times those from o.p. management.

Windamere, Tallaganda and Walcha Orchards will be developed at the outset mostly as conventional o.p. seed orchards, with careful management to maximise seed yields and reduce fluctuations in yield between years. However, it is proposed to develop small areas of Windamere and Walcha Orchards (perhaps a few hundred ramets at each site), as hedged sections where the methodology of SMP, using a mix of five or six pollens, can be developed, costed and evaluated. This will not be a purely experimental operation. The aim will be to produce commercially usable quantities of seed, which will be field-tested for quality against the routine o.p. seed from the orchard to see by how much realised genetic gain is increased. Estimates of costs and benefits will be sought as soon as possible from organisations using SMP in conventionally-designed orchards, with a view to possible wider use of this system in N.S.W.
The F.C.N.S.W. will aim to establish all seed orchards after Windamere and Walcha Orchards as c.p. orchards. Opportunities to establish these with second-generation clines of proven high GCA will not be available until about 2000, although superior second-generation clones as yet not tested for GCA could be employed much earlier, with a likelihood that these forwards selections are in fact superior (as discussed earlier). (This point will need confirmation by theoretical calculation before the use of untested advanced (second- or third-) generation forwards selections can be firmly recommended.)

Certainly, by about 2010, when the present orchards are to be phased out, there will be large numbers of reliably superior advanced-generation clones available. Any seed orchard system used will not rely on isolation of female flowers, as this would be far too expensive and difficult to organise on the required scale. The Western Australian HAPSO orchard at present appears the most promising design. Technology to control pollen in these orchards, and the methodology of management, will probably be well developed within 10 years' time, so that HAPSO's can be used as routine seed production facilities.

If the New Zealand Meadow Seed Orchard (Wooff, 1988) proves successful over the next few years, sites promoting abundant female flowering will be sought in coastal areas of N.S.W. (the South Coast is likely to be most suitable), with a view to testing this type of orchard.

A careful evaluation of the benefits versus the costs of producing c.p. seed in these types of facilities will need to be carried out early in the period of this Strategy, to determine the most appropriate ones for use by the F.C.N.S.W. The development of an efficient facility to mass-propagate juvenile cuttings from seedlings is a vital prerequisite for establishing c.p. orchards of any type. Resources should be devoted to bringing the best available genetic stock into production, rather than ensuring self-sufficiency in seed, if abundant seed production is difficult to achieve for some crosses.

Protection. Protection of orchards from fire and damage by grazing animals is of course most important. Fire protection is made easier if the site is near-flat, allowing slashing of grass between the ramets, to maintain a short green sward which will not carry a hot fire. An open grassy buffer zone should be maintained around the perimeter, by grazing if necessary. Grazing within established o.p. orchards will be avoided if at all possible, at least until all ramets are very well-established (about five years old). It is entirely incompatible with c.p. orchard management, where ramets are maintained at heights of below 2.5 metres, and at close spacings.

Weed control. Control of competing grass and weeds will be rigourously maintained, since they can seriously impede the early growth of ramets. The general aim will be to keep a weed- or grass-free zone at least 1.5 metres in diameter around all ramets. Optimum herbicide specifications will probably vary from site to site, and will tend to evolve with experience by local managers.

Fertilisation. The vigour of ramets and seed yields will probably both benefit from fertiliser application on most or all seed orchard sites. Once again, in all types of orchards, specifications will need to be developed site-by-site, aided by regular crop logging through foliar sampling, and by monitoring flower and cone yields of the various clones. It should be possible to fine-tune fertiliser prescriptions, in conjunction with irrigation if used (see below), even to the individual clone level in c.p. orchards, to maintain high flower and seed yields on most clones from year to year.

Irrigation. Irrigation is already installed in Windamere Seed Orchard, and is proposed for Walcha Orchard. Although irrigation is likely to lead to increased yields on any site, as well as reducing the year-to-year variation in the seed crop (Griffin et al., 1984), installing the systems is expensive. It may be wise to select sites for new orchards
where high yields are expected under natural rainfall, and where irrigation is not needed to keep ramets growing vigorously, or to site orchards adjacent to facilities which already have irrigation, such as nurseries.

In orchards where irrigation is used, it is proposed to monitor soil moisture profiles, preferably with neutron moisture probes, so that the soil can be maintained within prescribed limits of available moisture to optimise ramet growth and flower and seed production, and to ensure that the irrigation system is used to maximum efficiency. Prescriptions will vary according to soil type and topography, and will be worked out in conjunction with the Soils and Nutrition Section of the F.C.N.S.W. (WTFRD), and other organisations.

Application of the correct fertiliser and irrigation regimes is probably vital for the o.p. seed orchards, if they are to be efficient, cost-effective seed-producing units.

**Monitoring of clonal yields and health.** The relative vigour and seed and pollen production potential of clones in o.p. seed orchards will be monitored regularly from an early age (three to four years), to quantify variations among clones both within and between years. Such data will be used in decisions on culling o.p. orchards when they are 10 to 12 years old. They will also form the basis of decisions on varying fertiliser and irrigation regimes for all types of orchard.

**Seed collection.** Ramets in a conventional open-pollinated orchard rapidly grow out of reach of collection from the ground, so mechanical hoists or travel towers become necessary for cone collection. In New Zealand o.p. orchards, collection is done on contract by climbing (P. Bolton, Proseed New Zealand, *pers. comm.*), with climbers being paid per bag of cones delivered on truck. The cost of cone collection by climbing versus collection from a travel tower will be investigated for N.S.W. orchards, at least until they are pollarded (at age 10-12 years, if at all). One constraint on climbing is that the multiple stems of pollarded ramets may be brittle and dangerous for climbers; however, one or two early pollardings are not expected to result in multiple stems in older ramets (Brown, 1971).

Cone collection in control-pollinated and mass-pollinated orchards is a very cheap phase of the operation, as cones on hedged ramets can be reached easily from the ground or the back of a truck. This factor should be taken into account in any analysis of the relative costs of open- versus mass-pollinated seed orchard management.

**(vi) Seedling seed orchards.** Seedling seed orchards can provide a low-cost backup to seed production from clonal seed orchards. Although the greatest effort in seed orchard management will be devoted to the clonal orchards, the establishment of small areas of seedling seed orchards is advocated as a lower priority early in the period of the Strategy, to produce improved seed as a backup to Windamere and Vulcan Orchards.

The cheapest form of this type of orchard is a breeding population (or progeny test) thinned to the best trees of the best families. However, opportunities to do this in N.S.W. are very limited, and the prescriptions necessary to develop existing tests into seedling seed orchards (including very heavy thinning at four to five years) would tend to compromise the usefulness of these tests for evaluating between and within families. These tests are furthermore not located on sites likely to induce heavy cone production.

A more rapid method of developing seedling orchards is the extensive seedling seed orchard (ESSO), which will produce both improved seed and timber. It is proposed to establish ESSO's (if used) following the pattern used in Queensland for Caribbean pine (Nikles 1984), across two sites of expected high seed production potential, totalling about
20 ha. Bulked seed from 30 to 40 superior control- and open-pollinated families will be used. This seed will be collected mainly from second-generation plus trees in progeny tests, and also from proven first-generation clones in seed orchards. About 1000 trees ha\(^{-1}\) will be planted, and culled phenotypically to 175 ha\(^{-1}\) at age five years. This inclusion of a relatively large number of families and a heavy initial stocking will allow a selection intensity at culling of one tree in six, and should give a high likelihood of removing families which perform poorly. The genetic quality of the seed produced will be only slightly lower than that from clonal seed orchards (Shelbourne, 1969).

The establishment of these seed orchards will be fairly simple, the most difficult task being the selection of sites suitable for seed production, which are isolated from unimproved seed sources, and easily accessible. In practice, few resources are expected to be available for this work due to the far greater importance of producing the second-generation Breeding Populations, GCA-testing clones in them, and managing existing clonal seed orchards properly.

(c) Cuttings-Based Production Populations

The use of rooted cuttings to transfer outstanding genotypes from the Breeding Populations to routine plantations is an appealing alternative, or adjunct, to seed orchards. There are also opportunities to produce large amounts of plantable stock from special crosses made outside the formal Breeding Populations.

(i) Advantages of mass vegetative propagation. Techniques for the vegetative propagation of radiata pine have been available for many years. However, the vegetative mass propagation of selected families or clones of the species on a commercial scale is a relatively recent occurrence. For example, Tasman Forestry Ltd. in New Zealand planted out 13,000 rooted cuttings in 1970; by 1984 they were setting 750,000 cuttings in their production nursery (Arnold and Gleed, 1985).

Advantages of vegetative propagation of improved material have been discussed by several authors over the past few years. The main advantages are (Burdon, 1986; Clarke and Slee, 1985; Lindgren, 1983):

a) A reduction in the lead time in getting genetically advanced material from the breeding population into production for routine plantations. This is the first and foremost of the advantages of mass vegetative propagation of control-pollinated families versus seed orchards. (Included here would be the augmentation of planting stock from seed produced in control-pollinated seed orchards.)

b) There may be a possibility of utilising specific crosses or clones within these crosses, which perform well on particular sites.

c) Better form characteristics of cuttings versus seedlings. Plantations of cuttings generally have straighter stems and finer branches than seedling plantations.

In New Zealand, final crop returns are expected to favour cuttings over seedlings, despite a greater unit cost to raise cuttings. For instance, Menzies and West (1982) quote present net worth figures of $949/ha for plantations established using cuttings, compared with $803/ha for plantations established with seedlings, at clearfelling age.
(ii) Development of cuttings-based production populations in N.S.W. The incorporation of mass vegetative propagation into the Breeding Strategy for radiata pine in N.S.W. is regarded as very important. This is because of the relative speed with which highly-improved material may be brought into plantations, and particularly because mass propagation of particular families or clones may provide the only practical method of multiplying specific genotypes for routine planting on specific types of sites, where this is necessary, as on ex-pasture or other sulphur-deficient sites, where fertiliser technology cannot cope.

The ideal clonal strategy, of mass-propagating excellent individual trees of known pedigree discovered in tests, is not yet possible, due to the fact that trees of a physiological age greater than about four or five years do not yield a usefully high percentage of rootable cuttings, and ringbarking pretreatment is necessary for cuttings propagation of aged material. Identification of promising full-sib families or clones for later mass-propagation is generally based on tests containing several families or identified clones within-families. In the latter case, clonal variation within families may be exploited, with only the best individual clones being reproduced en masse (true clonal forestry).

(iii) Development of planting stock for problem sites. The primary aim in the use of vegetative propagation in N.S.W., in the earlier stages of the Strategy, will be to develop cuttings planting stock able to survive and grow successfully on three major 'problem' site types.

- Improved ex-pasture sites, for which bulk seed orchard stock is not expected to be suitable.
- Dothistroma-susceptible sites over several geological types in the north of N.S.W.; probably these will be served adequately by seedlings from Walcha and Tallaganda Seed Orchards, possibly augmented by mass propagation of cuttings. However, outstanding genotypes resistant to Dothistroma and of superior growth and form, should be developed.
- Very low fertility sites (particularly those low in phosphorus); likely to be served in part by the Sedimentary seed orchard Production Population; however, the development of special well-adapted genotypes is desirable.

Proposals for each of these site types are detailed below:

(i) Improved ex-pasture sites. Ex-pasture sites, especially those previously improved with clover and heavily topdressed with superphosphate, cause severe problems for the establishment and growth of radiata pine. They often have a very high nitrogen content, associated with low levels of sulphur and boron, as well as an imbalance of phosphorus, calcium and magnesium. Symptoms in pines include high mortality on the worst sites, large branches and/or a wobbly stem (Horne, 1986). Established stands often have very high growth rates, but extremely poor stem and branch form. By the year 2000, up to 15 000 ha of improved pastures are likely to be planted, in addition to at least 10 000 ha of unimproved pastures, covering geological types ranging from basalts on the Northern Tablelands to granodiorites and high-fertility sediments in Albury and Bathurst Regions.

A special small genetic improvement programme will be instituted, to develop a suite of control-pollinated families, and possibly clones, for improved ex-pasture sites, whose cuttings will survive, grow well and maintain a level of stem straightness and branch quality above a minimum acceptance level (to be prescribed). Operations under this
programme (and other similar programmes) will be separate from those in the on-going improvement of the Breeding Populations, although the programme will largely draw on these Populations for genotypes.

Approaches to be used in this programme are generally similar to those proposed in an operational programme for pastures in north-east Victoria (Pederick, 1988), and involve screening a range of full-sib families and clones of N.S.W. origin, and some selections from other breeding organisations. Proposed operations are detailed below.

Field-select cuttings: Cuttings should be taken from well-formed individual trees in two to three year-old plantations of seed orchard origin, on sites showing a high level of deformity, for routine planting on this type of site. This is essentially a stop-gap measure, which can be expected to lead to some improvement before highly-selected pedigreed genotypes can be produced. Cuttings of a physiological age of three years are considered most likely to show both good form and growth rate on pasture sites (Menzies et al., 1985).

Selection of clones from established progeny tests: There is only one progeny test on highly-improved pasture in N.S.W. in which selection of genotypes can commence in the near future. progeny Test Q14132, in Hilltop Section of Bondo State Forest (Albury Region), contains progenies of 16 first-generation clones from Green Hills Seed Orchard (also in Vulcan Seed Orchard). This test will be assessed for stem and branch form at age nine years, to determine clones with a relatively high proportion of well-formed progeny. Seed from suitable clones can be procured from Vulcan Orchard to produce seedlings for pasture sites. Larger numbers of three year-old cuttings may also be produced from these seedlings, which will have improved form over the seedlings. A similar approach is being followed with two clones in Victoria (Pederick, 1988).

Production of full-sib families for mass vegetative propagation: Cuttings of highly-selected full-sib families will be likely to give the greatest gains in form. Promising clones from the Hilltop progeny test will be crossed with one another. The original first-generation clones will be used, as these are presently available in clone banks, and controlled pollination can begin in the near future. Carson (1986b) and Cotterill et al. (1987) consider that mating parents of high GCA (superior performance) gives a high probability of generating outstanding crosses for selected traits.

Cuttings will also be produced from about 30 crosses made in N.S.W. in 1980-83, as part of the Co-operative Diallel mating project of Research Working Group 1. Seed of many of these crosses is still in store. Although the parent clones were not specifically selected for performance on pasture sites, they are generally of a high GCA for stem and branch form.

Infusion of genes from the Guadalupe Island population: The Guadalupe population of radiata pine appears from Victorian trials to have an ability to retain superior stem form on improved pastures (Pederick, 1988), and hybrids with outstanding Australian clones should also be well-formed. A few (two or three) Guadalupe ortets of outstanding growth and form will be selected in the 1973 plantings adjacent to Wee Jasper Gene Pool Trial. These will be crossed with selected first-generation N.S.W. clones to give 12 to 18 full-sib hybrid families. To enable the crosses to be carried out soon, pollen will be collected from the Guadalupe trees.
Cuttings of the 50 to 60 full-sib families from the three sources detailed above will be tested in small progeny tests over several pasture sites. Six or seven cuttings per clone will be used in these and other clonal tests. This number is recommended by Simpson and Ades (1988). These tests will be assessed at five to six years, with the aim of retaining the best 25% of families for growth, and particularly form, for mass vegetative propagation on a production scale.

**Later production of full-sib families:** Large numbers of progenies of first-generation plus trees (about 300) are planted in two progeny tests on ex-agricultural land in Mt. David S.F. in Bathurst Region. These tests will be searched for trees of outstanding form in six to seven years of age, if the stands show severe levels of deformity. Second-generation selections will be used in some families, if ramets of the first-generation ortets are not available in clone banks.

The relatively few selections made will be crossed together in a similar fashion to the earlier selections and with Guadalupe clones. The number of full-sib families to be produced from these selections will depend on the availability of resources, and the degree of success evident from earlier work.

**Testing of families and clones from other organisations:** A.P.M. Forests and the Victorian Dept. of Conservation, Forests and Lands (CFL) have begun testing programmes on pasture sites. Screening of the most promising full-sib families and clones produced by these organisations should be carried out on a co-operative basis, and they could ultimately screen genotypes produced in N.S.W. Such co-operation is to the advantage of the F.C.N.S.W., enabling us to share the load of testing (thus covering more sites), and screening more genotypes. However, establishment of tests of large numbers of genotypes should not be carried out at the expense of the small crossing programmes proposed to generate well-adapted families in N.S.W.

There would be an opportunity to select individual clones within the specific crosses tested, giving larger gains. However, there are logistical difficulties with this approach. The inherent superiority of candidate clones needs to be conserved without genetic change or further maturation during the test phase; one also has to be able to multiply selected clones to useful numbers at a reasonable cost (Carson, 1986a). It is not proposed at this stage to venture into clonal forestry per se for these sites, although clones already developed and donated by other organisations should be tested (see above).

The programme for producing genotypes adapted to pasture sites is considered to be the most important of the "problem" site projects, as large areas of this type of country are being purchased, and the establishment of plantations of acceptable quality has proved very difficult on these site types. It should be commenced as soon as possible and carried out with equal priority to the development of the second-generation Breeding Populations.

(ii) *Dothistroma*-susceptible sites. Large areas of present and proposed plantation in the north-east of N.S.W., on a range of geological types, are susceptible to *Dothistroma* needle blight. At least 10,000 ha are involved. Existing and proposed clonal seed or chards are expected to produce generally resistant planting stock. The genetic variability of *Dothistroma* resistance has been found to be largely additive, implying that genetically-resistant strains can be produced by seed in clonal orchards (Wilcox, 1982).
The development of resistant families and clones through a small special programme of producing and testing superior specific crosses is considered desirable, so that areas of elite stands can be established as well. This strategy should reduce the need for spraying to control the disease (costing about $12 per ha in New Zealand in 1984 - Shelbourne et al., 1986), and even for fertilising to correct nutrient problems on basalt soil types.

It is likely that some clones or crosses suitable for pasture sites will also be suitable for Dothistroma-susceptible sites on basalt. Therefore, specific crosses proposed for testing on the pasture sites (including the crosses made in the 1980-83 Diallel programme) will also be screened on these sites. Additional crosses may be made between first-generation clones whose open-pollinated progenies showed superior growth and form in Progeny Test Q14601 (established 1966). These clones are already present in clone banks.

Clonal trials established in Nundle S.F. in 1982 and 1984 will give a guide in the near future to clones of high resistance and also superior growth and form on basalt sites. The 1984 trial contains 30 clones of the outstandingly-formed family 20080 x 20055, which would yield valuable information on the variation of clones within a family and likely gains from clonal selection. Selection of a suite of about 10 to 15 clones (1:8 to 1:5.5 selection intensity) is proposed from these trials, to be mass-propagated for routine use. The original donor plants of these clones are held by C.S.I.R.O. and Treegenes Pty Ltd, so cuttings may have to be obtained on contract.

Resistant specific crosses and clones will be obtained from New Zealand, if possible, for testing on our sites and possible inclusion in the suite of routinely-used genotypes. There is also the opportunity to provide a testing service in N.S.W. for other organisations in Australia wishing to have their selections screened for Dothistroma resistance. This would yield information of use to our programme as well.

Operations under this small programme should generally receive a lower priority than those for the pasture sites and the development of the mainstream Breeding Populations, at least until the pasture site problem is solved. However, work in this Dothistroma programme is in fact in progress, and many of the operations will overlap with those proposed for pasture sites. To this extent, these operations should logically proceed together.

(iii) Low-phosphorus sites. These site types are described in the discussion of the Granite/Sedimentary Breeding Population. They include very low fertility sites on schist, phyllite, sandstone and acid volcanic geology, totalling up to 18 000 ha. Bulk seed from seed orchards, such as parts of Windamere Seed Orchard, comprising clones selected for growth (particularly) on sedimentary sites, should produce plantations of improved growth. More striking gains can be expected from mass vegetative propagation of specific crosses selected for superior growth on these sites, especially those which respond to phosphorus fertilisers.

A small number of progeny tests and clonal trials are already established on these site types, and can be used as sources of select material. Selection of first-generation clones of superior growth rate and form can be carried out on the basis of growth assessment in two progeny tests established in 1981 (Q14135 in Murraguldrie S.F. and Q14410 in Jenolan S.F.). A similar strategy to that described for the pasture sites could be implemented, that is, crossing the best GCA parents over the two tests in a small half-diallel, to generate specific crosses to test (including a fertiliser treatment), of which about 15 would be selected for routine use.

The large F.C.N.S.W./C.S.I.R.O. clonal selection trial at Essington State Forest, established in 1984, contains 100 clones over 20 control-pollinated families. Assessment of growth
and form in this trial in about 1990 will reveal families and clones within families which grow well on this infertile sedimentary site, and respond to rock-phosphate application. The most promising can be mass-produced for routine use. The mother plants are held by C.S.I.R.O. and the South Australian Woods and Forests Department, so cuttings of select clones may have to be procured from these organisations.

The development of genotypes adapted to these low-fertility sites will receive lower priority than the programmes for the other two ‘problem’ sites, since acceptable growth rates can probably be achieved with fertilisers alone.

(iv) Development of cuttings-based production populations for general planting. As time goes on, the F.C.N.S.W. will aim to utilise the large genetic gains advantages from mass vegetative propagation of superior specific crosses in all plantations. Indeed the greatest commercial gains from such a production strategy can be expected to accrue on the high-quality sites without severe nutritional or disease problems. In practice, the great majority of these crosses will be produced in c.p. seed orchards, as proposed earlier, with rooted cuttings planting stock being produced. A c.p. seed orchard should be viewed as a facility to produce a flexible range of crosses, probably yielding larger amounts of seed of a favoured mix of crosses, but with the flexibility to add or subtract other clones more or less at will.

Special crosses, of which only small amounts of seed are needed, may of course be made outside these orchards (e.g. in clone banks), using the most advanced clones available at the time. This work could be commenced at any time, even in the near future, using first-generation clones of proven GCA, or second-generation clones (as yet of unproven GCA). However, given the limitations of resources, such work will remain subordinate for a considerable time to the ongoing improvement of the Breeding Populations and the development of special cuttings production populations for the first two ‘problem’ sites, as detailed earlier.

The initial aim will be to establish small areas of very high quality cuttings which can be marketed as veneer logs, using cuttings from seed produced early in the period of the Strategy, in mass-pollinated orchards (if used), or from particular clones in o.p. orchards. A study by Spencer (1988) showed that logs of the same size grown from field-select cuttings at age six years produced 8% more volume and 107% more veneer quality material compared with logs grown from seedlings. Results from cuttings of select families are expected to be even more favourable.

The ultimate development of a large-scale Cuttings Production Population (partly as an adjunct to the seed orchard Production Population and partly as a separate entity) should not be carried out in lieu of, or as a higher priority than, improvement of the Breeding Population. It is important to have an active, ongoing breeding programme to generate favourable combinations of genes, or opportunities to cross very high GCA parents (and the supply of superior clones) will dry up (Boomsma, 1987). This important message is also emphasised by Lindgren (1983), and Carson (1986a), who states that clonal forestry should be adopted as a complement to an existing breeding programme rather than as a replacement for it.

Embracing clonal forestry *per se*, as advocated by Libby and Rauter (1984) and Clarke and Slee (1985), as the main production population strategy, would have logistical difficulties. The perceived advantages of clonal forestry over vegetative multiplication of progenies from control-pollinated orchards may not be great. Carson (1986a) considers that the latter option allows the utilisation of many of the advantages commonly attributed to clonal forestry (e.g. Libby and Rauter, 1984), while having additional advantages of relatively cheap and efficient screening (of specific crosses), easier archive management, and lower nursery costs. Carson (1986a) further considers that the advantages and
practicability of allocating genotypes to specific sites need to be investigated using stock of polycross or full-sib family origin. If these can be proven, extension to complete clonal forestry could logically follow. Clarke and Slee (1985) list a number of questions which need to be answered before clonal forestry could be fully integrated with radiata tree improvement programmes, such as the extent of clone x site interaction, and how large a concern inbreeding is.

**Facilities for raising cuttings.** Use of the option of mass vegetative propagation of specific crosses on pasture sites is likely to be initiated within the next few years in N.S.W. Facilities for the production of high-quality cuttings of families, for both the testing phase and, five to six years later, for commercial production on a large scale, will need to be developed int the near future by the F.C.N.S.W. If the aim is to plant all pasture sites alone with cuttings, very large numbers per year will need to be produced (possibly up to one million). To supply such numbers, a large and carefully-managed special nursery will be required, such as that described by Arnold and Gleed (1985) in New Zealand.

Until the F.C.N.S.W. produces its own specific crosses for mass propagation, limited numbers of cuttings of proven clones and families can be purchased from other organisations, to fill some of the requirement.

As time goes on, the number of cuttings required for plantations can be expected to rise, especially as control-pollinated orchards are established as the major source of planting stock. However, it seems unlikely that cuttings will entirely replace seedlings in N.S.W. plantation programmes until well beyond the turn of the century, if at all. Even if clonal forestry were adopted as the major strategy to replace seed orchards in the production population, this would probably not be until 2010 or later.

The economies of mass-production of cuttings of radiata pine in nurseries are still unfavourable compared with those for seedlings. For example, New Zealand nursery gate prices per 1000 plants show cuttings to be twice as expensive to produce as seedlings from control-pollinated seed orchard seed and three times as expensive as seedlings from open-pollinated seed orchard seed (Carson, 1986a). The economics of producing large numbers of cuttings can be expected to improve as increasing experience is gained and shared throughout Australia and New Zealand.
DEMONSTRATION PLANTINGS

These are plantings designed to clearly demonstrate gains from past breeding to administrators and others influencing the direction and funding of a tree improvement programme. Realised gains, although they may be great, are often difficult to demonstrate in progeny tests because of small plot sizes. Without such plantings, forest managers will not be able to distinguish changes in yields and quality due to orchard seed from improvements due to concurrent developments in silvicultural techniques (Eldridge and Matheson, 1983).

Demonstration plantings would take the form of small blocks (e.g. 49- or 64-tree plots replicated four or five times) of a few superior genotypes, allowing an easy visual comparison with blocks of unimproved stock, on sites representative of plantation areas. The plots should be replicated at each site to allow assessment and analysis of their productivity. A Latin square design is effective for this purpose.

Early demonstration plantings established by the C.S.I.R.O., to demonstrate gains from Tallaganda Seed Orchard seed, are described by Eldridge (1982). Further plantings were established by the F.C.N.S.W. on four contrasting sites in Albury and Bathurst Regions in 1982 and 1983. 64-tree plots of Vulcan, Green Hills and Saxton's Seed Orchard (Victoria) seedlings are compared with plots of seedlings raised from seed collected on the actual sites of the trials. These plantings are due to be assessed at age six years in 1989, and later ages.

Co-operative demonstration plantings (Australasian Breeds Trials) of 19 different improved seedlots were established in 1988 in Albury and Bathurst Regions, as part of a series of plantings throughout Australia and New Zealand. There are seven Australian seed orchard seedlots (including Vulcan Orchard), six New Zealand commercial improved seedlots from New Zealand, as well as a local routine clearfelling seedlot.

The plantings consist of two designs: 6-tree row plots and 64-tree square plots. The larger trials are designed to monitor performance over 15 to 20 years of silvicultural treatments. They are planned to be assessed at ages three, six and 10 years, following first thinning (about 13 years), and later.

Demonstration plantings will be established in future to display the expected superiority of open- and control-pollinated seedlots from the new second-generation seed orchards, once these are fully productive. Vulcan Seed Orchard and clear-felling seedlots will be used as controls. Smaller-scale tests will be planted at the same time, to quantify this gain. Block plantings of seedlings and cuttings of proven superior families will also be established as demonstration areas, as these become available.
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The Breeding Strategy for Radiata Pine in New South Wales Part II - Proposed Operations


