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ACTING CONSERVATOR OF FORESTS
STATE HEADQUARTERS

TITLE: A plan for breeding *Pinus radiata* in Western Australia.

SUMMARY:

A long term plan for the breeding of radiata pine in Western Australia is presented. The plan reviews the progress and advances of the first 20 years of the programme and an outline is given for the future development of the species that will both continue the cumulative improvements already achieved and maintain the genetic diversity. Schedules are included detailing the availability of improved genetic material for the establishment of plantations either by seedling or clonal propagation.

The plan is to develop two breeding populations leading to different production populations, one for general afforestation and the other for planting of all potentially susceptible *Phytophthora cinnamomi* sites.

Continuing collaboration of all radiata breeders in Australia is essential to the maximisation of benefits in this plan. The Western Australian population will serve as the main base for W.A. production orchards etc. and they will be complemented by the best genetic material available through exchange with other programmes.

This is a first-draft of the plan. The plan is presented for comment from managers within the Department and will be copied to members of the "radiata task force" and members of the Australian Forestry Council Research Working Group on Forest Genetics for comment.

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INTRODUCTION

The long term nature of forest tree breeding implies a committment by the organisation for its financing and staffing continuity for the perpetuity of the project. Other priorities and pressures for researching will always lead to speculation about the need to continue and to the actual economic value of the research. Published results show increases in yield and improvements in quality for our Pinus pinaster and increased disease resistance of P. radiata but although these results are acknowledged, they go unnoticed because they are not quantified in terms of money.

The management model for P. pinaster, embracing the concepts of intensive management and applied genetics for more production and greater efficiency shows that tree improvement is a paying proposition. And there is an extra payoff in the Sunklands where increased disease resistance of P. radiata to Phytophthora cinnamomi is a uniquely genetic effect that could not be achieved by any other means. International literature supports tree improvement as a good economic investment, "perhaps even the best of all possible forestry investments" (Zobel, 1978).

Most pine plantations in Australia are currently grown from ochard seed and the main task is to now improve the genetic quality of this seed. Most of the future improvement in the genetic quality of Australia's orchard seed will come from a new generation of orchards begun in the early 1980's. These orchards will contain mostly 1.5 or 2nd generation clones.

The solution of many of the problems facing forestry, particularly the conflicts between alternative uses of the same forest lies in intensive management, encompassing genetic improvement, of part of the forest area for wood production. There is an opportunity to concentrate wood production on a smaller land base permitting the larger remaining areas to be managed more flexibly toward other objectives.

At this time when our organisation is undergoing major restructure and land management functions are being discussed, it is opportune to review the Department's pine tree breeding programmes. A plan for the breeding of radiata pine is presented for discussion and endorsement.

SCOPE OF REVIEW

Nearly all of the Australian programmes breeding Pinus radiata have reached the end of the forest generation. The lack of an overall plan and particularly the uncertainity of the breeding methods for future generations, has resulted in a 20 year generation interval for this first generation. A promised mass production of seed to establish plantations of fast-growing, fine-branched, narrow-crowned trees seems unlikely until at least the third generation of seed orchards (Eldridge, 1983). To maximize commercial gains, structured breeding plans incoporating reduced generation intervals are required.

Early results from first generation seed orchard progeny are clearly superior to that of non-orchard sources. Pederick and Eldridge (1983) reported that initial orchards have yielded plants that grow at least 10 per cent faster in volume than unimproved plants and the gains many even increase with age. Trees of orchard orgin were also straighter and had thinner and more frequent branches than the controls.

As soon as progeny information is available about the clones used in the first generation orchard, the genetic quality of the orchard can be improved by removing (culling) the poor performance clones. For example, Pederick and Eldridge (1983) calculated an increased average gain in volume of young trees derived from the rogued (culled) orchard from 7.4% to 10.2% by removing 12 poor performance clones from a 50 clone seed orchard in Victoria. They were also able to increase this gain to about 16% (i.e. double) by the establishment of a "1.5 generation" orchard (knowledge of breeding values of clones).

Data from Western Australian progeny tests and yield trials are in accord with reported gains from Australasian tests. This is discussed in the section on Advances in the first phase of the W.A. breeding plan. Some data is shown in Appendix 1.

The first generation of breeding radiata pine in Australia has made a distinct improvement in growth rate and tree form. In a recent economic analysis of the gains achieved from a radiata pine orchard, Wright and Eldridge (1983) calculated that, by spending $10 to $20 per hectare on improving seed, nett present values of plantations would be several hundred dollars higher and internal rates of return would exceed 20%.

Continued investment in breeding seems certain to result in further genetic improvement in second, third and subsequent generations.

A plan for the breeding of radiata pine in Western Australia is presented. It is logically divided into five segments that detail the historical time frame, major objectives and progress of the plan. The plan has, and will continue to reply upon considerable co-operation and co-ordination with other Australian states breeding radiata pine to achieve maximum increasing gains and to provide a broad genetic base to ensure these advances in perpetuity.

The major segment of the plan is phase 5 (research and development). Objectives are to continue the cumulative improvements aready made in genetic quality of seed used to establish plantations, and to maintain genetic diversity i.e. the ability to adapt to changing environmental and economic circumstances. Shortened generation intervals of about 14 years are proposed.

RADIATA PHASE 1: 1960-70 (commencement)

All southern Australian states began tree breeding programmes for Pinus radiata during this period. Programme objectives were for increased yields of high quality wood through multiple-trait selection. The foundation of the programme was plus tree selection with very high selection standards. Large areas were searched for very few plus trees on the assumption that heritability and additive genetic variance would be fairly high for all characters.

Gene pool:

* 1962-64; W.A. plantations at Mundaring, Margaret River and Grimwade over 20 years of age were searched for plus trees. From this limited area, 20 plus trees were selected. Scion material was collected for grafting and establishment at the Mundaring clone bank.

* 1964-65; additional plus tree selections were imported as scions from Canberra (10), New South Wales (9), Victoria (13), South Australia (11) and New Zealand (3). Grafts were planted at the Mundaring clone bank and Gleneagle seed orchard.

Breeding population:

* 1969-74; progeny tests were mainly based on open-pollinated seed in seed orchards.

* The first tests, planted in 1969 (32 families - Collie) and 1971 (60 families - Collie and Blackwood Valley) used polycross seed of Canberran, South Australian and Victorian origin. Test objectives were to rank parents for breeding values, demonstrate genetic gains and examine genotype x environment interactions.

* 1972 was devoted to the planting of the International gene pool at Grimwade and Kirup. Seed of 319 seedlots, mainly wind-pollinated progenies collected in seed orchards, was provided from 13 different breeding programmes. Test objectives were the establishment of a combined genetic variability pool, a source for second generation selections, evaluation of the genotype x environment interaction and development of seedling seed orchards.

* Local selections were included in comprehensive progeny tests for the first time in 1974. The eleven W.A. clones used in the Gleneagle orchard were collected as polycross seed and trials were planted on major plantation site types at Donnybrook sunklands, Blackwood Valley (later destroyed by rabbits) and yellow sands at Yanchep. Principal objective was the ranking of parents for breeding value, as well as demonstration of gains and evaluation of genotype x environment interactions.

<u>Production population:</u>

* 1965-68; a 4.5 ha seed orchard using 40 clones from the gene bank was established at Gleneagle. This was later abandoned, in 1976, because of very low cone yields.

* 1967-71; seed production stands were developed at Grimwade A section. Together with third thinnings cone collection, they were to provide an interim source of improved seed prior to the availability of orchard seed.

* Yield trials were planted in 1973 at Grimwade, Blackwood Valley and Yanchep. Test objective was to evaluate the potential of improved seed on the establishment and management of plantations. Treatments included orchard, seed production stand, crop tree and routine seed planted on large plots at either 1000 or 2000 spha.

Advances:

* One of the major objectives of the early progeny tests was to show benefits from tree breeding. Data from Appendix 1 indicates that this objective has been achieved:
  a) increased volume production (diameter and height) of the order of 10%; will lead to a shortening of the rotation and earlier returns from intermediate yields.
  b) reduction of planting and thinning costs due to the better quality and more uniform plants i.e. orchard seedlings will yield a greater number of straight, smaller limbed trees thus requiring the planting of fewer seedlings for the selection of the growing crop of sawlog trees. Cheaper systematic thinning techniques can be applied in the more homogeneous stands established at a wider spacement.
  c) an increase in the percentage recovery and in the grade of the processed product due to improvement in stem form and branching properties.

* Another major objective was the ranking of breeding values of clones in the Australian population for W.A. afforestation. This has been achieved (Appendix 2). Information has been used to upgrade the genetic quality of the Manjimup orchard by the removal of the poorer performing clones. The information is also being used in the creation of the new "1.5" and 2 generation seed orchards proposed in phase 4 of this breeding plan (Appendix 2a).

* A third objective was the evaluation of the importance of genotype x environment interactions. Generally family performance has been similar whether grown on former pasture or bushland sites and also on the Sunkland site, although rankings may be changed on the latter site due to variable susceptibility to *Phytophthora cinnamomi*. Matheson and Raymond (1984), reported a loss of potential gain using a single

Australian population; regionalization of breeding programmes was suggested as one solution but the better solution would be to omit interactive families which seem to be particularly susceptible to environmental variation.

RADIATA PHASE 2: 1970-80 (enrichment)

During this second decade the Donnybrook Sunklands was proposed for a major P. radiata afforestation programme. This project envisaged the conversion of some 60,000 ha of degraded dieback-infested native forest to pine plantation over a period of 30 years. A limitation to the planting of radiata pine was the lack of a proven genetic seed source adapted to this hostile environment. Progeny trials of the Australasian breeding population were established in the Sunklands to identify suitable clones for orchard development.

The provenance collections made by Eldridge (1978) were planted at the Sunklands in 1979 and will provide a useful resource of plants for breeding in the future.

Local plantations at Pemberton (Pimelia), Grimwade and Harvey (coast) were intensively searched for plus trees; 27 plus trees were selected and added to the breeding population.

Western Australia's major radiata pine seed orchard was planted at Manjimup on a site that should have greater flowering potential than the poor Gleneagle site.

Gene pool:

* The Pimelia plantation (125 ha) was intensively searched for plus trees in 1970. The search revealed 74 good trees, 21 of which were considered candidate plus trees. Because of the high standards imposed, only 5 were classified as plus trees and added to the clone bank and orchard.

* Poor quality areas at Grimwade (32 ha) were searched in 1971, yielding 14 plus trees. These new selections were planted in the seed orchard and clone bank.

* Harvey coastal plantations (SN 1899) were searched in 1974; this yielded 7 plus trees from 31 ha searched.

Breeding population:

* Progeny tests in 1976 used half-sib and full-sib seed supplied from the NSW programme. Objectives were to rank the breeding value of these clones and to provide a pedigree source for second generation selections.

* Full pedigree seed provided by CSIRO was planted out in progeny tests in 1977 and 1978. Principal objective was to provide a source for second generation selections.

* The major planting in 1979 was the natural populations of *P. radiata*. Objectives were to provide a long-term and variable stock of genetic variation, a new source for selection of plus trees and the identification of the best Californian sub-populations for particular environments. A progeny test to evaluate early W.A. selections was also planted.

* In 1980, the Grimwade marginal site selections were planted out in a large progeny trial at Baudin. Test objective is to rank the breeding value of these parent trees.

* Open pollinated seedlots from the A.C.T. and Tasmanian breeding population were planted in a Vasse trial in 1982. Again the objective was to rank parental breeding values.

* Parents from the Victorian and NSW breeding population were planted in 1983, in a trial in the Vasse plantation. Objectives are to rank parents on their breeding value.

Production population:

* 1969-72 West Manjimup seed orchard (13 ha). The orchard was established using grafts of 92 clones planted at 370 s.p.ha.

  7 ha of the P69-70 area was culled to retain 36 clones at a stocking of 155 s.p.ha in 1979; this culling was based on information of progeny performance in Western Australia and other Australian tests and on ramet shape in the orchard. Additional culling was carried out in 1983 reducing the stocking to 100 s.p.ha.

  The remaining 6 ha (P71-72) was culled in 1982 of *Phytophthora cinnamomi* susceptible clones to develop a *P.C.* tolerant seed source. 40 clones with good form, vigour and *P.C.* tolerance now constitute the orchard, stocking is 130 s.p.ha.

Advances:

* First cone harvest from the West Manjimup seed orchard was in 1976 when 64 kg seed (SN 5087) was collected. Orchard was in full production in 1978 yielding 195 kg seed (SN 5099). A maximum harvest of 327 kg seed (SN 8301) was achieved in 1983; this was equivalent to an orchard production of 25 kg seed per orchard hectare and makes it one of the higher yielding radiata orchards in Australia.

  However culling to enhance the genetic quality and pollarding to facilitate cone collection is expected to reduce the average orchard yield to about 12-15 kg/ha, i.e. orchard yield of 160-200 kg. Based on average 11 000 plants raised per kilogram of seed sown in the nursery and a planting density of 1 000 per hectare in the field, the orchard will only cover the planting of between 1700 - 2200 ha per year.

If the radiata programme is to exceed 2 000 ha per year an additional planting source is immediately required. Cone collection from unimproved forests would be a backward step and is not advocated. Instead the use of cuttings of selected radiata pine is recommended. Proposals are discussed in Phase 4 of the breeding plan for the immediate production of 30 000 woody cuttings (60 ha) leading to future production of 100 000 woody and fascicle cuttings (200 ha).

Scheduling of seed orchard populations is documented in Appendix 3. As there most likely will be a shortage of improved seed every endeavour should be made to purchase orchard seed over this period from elsewhere in Australia e.g. Saxtons seed orchard.

RADIATA PHASE 3: 1979-85 (*Phytophthora cinnamomi* disease resistance).

Extensive planting of *Pinus radiata* in the Sunkland commenced in 1974. Seedling and young tree deaths were found to be consistently associated with root infection by *Phytophthora* spp. These deaths were scattered and could be due to the distribution of the pathogen in the surface soil or there could be genetic variation in resistance. A pot trial was initiated in 1978 to see if there was variation and if it was heritable. This initial work, reported in Butcher et al. (1984), established that resistance in *Pinus radiata* to *Phytophthora cinnamomi* was under strong genetic control and that the genetic control of resistance also acted in the field.

Objectives of this phase were to identify genotypes that were tolerant to *P.C.* for the future development of a tolerant seed source, and to show that genetic tolerance is effective against a range of *P.C.* isolates and stable over the growing rotation of the tree.

Breeding population: glasshouse screening tests.

* Series I - 1979/80; 18 parents from West Manjimup seed orchard. Test objective was to determine genetic variation and heritability as well as a ranking of parents on disease resistance. Split-plot design with inoculation(1 isolate) treatments applied to single family pots.

* Series II - 1980/81; 31 parents from West Manjimup seed orchard. Test objective was to determine genetic variation and heritability as well as a ranking of parents on disease resistance. Split-plot design with inoculation (1 isolate) treatments applied to single family pots.

* Series III - 1981/82; 35 parents from West Manjimup seed orchard. Test objective was to rank parents on disease resistance and to look at host x pathogen interaction. Split-plot design with 2 P.C. isolate treatments applied to single family pots.

* Series IVA - 1982/83; Wanneroo - parents from W.A. (13), A.C.T. (17), Tasmania (40) and Victoria A.P.M. (55); multi-family pots and 2 P.C. isolate treatments, 5x5x5 cubic lattice design.

* Series IVB - 1982/83; Como - parents from W.A. (12), A.C.T. (17), Tasmania (36) and Victoria A.P.M. (35); single-family pots, 2 P.C. isolates, 10x10 triple lattice design.

Series IVA and B objectives were to rank parents from the Australian breeding population on disease resistance.

* Series IVC - 1982/83; Como - host x pathogen interaction; 5 parents (2 tolerant, 3 susceptible) and 8 different P.C. isolates, multi-family pots with a split-plot design.

* Series VA - 1983/84; Como - parents from W.A. (10), Victoria (19) and N.S.W. (20); multi-family pots, 8 P.C. isolates to each pot; 7 x 7 balanced lattice.

* Series VB - 1983/84; Como - as for VA except that single family pots were used; 7 x 7 triple lattice.

Series VA and VB objectives were to rank parents from the Victorian and N.S.W. breeding population on disease resistance.

* Series VC - 1983/84; Como - host x pathogen interaction; 8 parents (4 tolerant, 4 susceptible) and 10 P.C. isolate treatments including the A1 mating type and control, multi-family pots with a split-plot design.

* Series VIA - 1983/84; Como - natural populations; Ano Nuevo (10), Monterey coast (10), Monterey inland (9), Cambria (10) and Cedros Island (10); multi-family pots, 8 different P.C. isolates per pot, 7 x 7 balanced lattice design.

* Series VIB - 1983/84; Como - natural populations; Ano Nuevo (12), Monterey coast (12), Monterey inland (12), Cambria (12), Guadalupe Island (12) and Cedros Island (12); multi-family pots, 8 different P.C. isolates per pot, 8 x 9 rectangular lattice.

* Series VIC - 1983/84; Wanneroo - domesticated populations; W.A. (21), S.A. (21), New Zealand (21) and South Africa (21); multi-family pots, split-plot design of control and inoculated (8 P.C. isolates/pot) treatments.

  Series VI objectives were to evaluate variances within and between populations, heritabilities, mode of gene action.

* Series VII - 1984/85; Como - parents from W.A. (4), S.A. (18 + 5), South Africa (22 + 4) and New Zealand (5 + 1). Series VIIA multi-family pots with 4 P.C. isolates, 7 x 7 balanced lattice design. Series VIIB single-family pots with 4 P.C. isolates, 7 x 7 triple lattice.

  Objectives are to evaulate some of the parents from the South Australian, New Zealand and South African breeding population for disease resistance.

Breeding population: field screening tests.

* RS 17(1980) - Baudin II, *Pinus radiata* families (27), orchard sources (3), *P. pinaster* and *P. taeda* planted as single tree plots on a severely infested dieback site; split-plot treatments of natural and natural plus applied inoculum. Objective was to correlate the field and glasshouse test results on genetic variability,

to study disease expression with time and to evaluate sub-lethal infections on growth rates.

* RS. 18 (1981) - Baudin 12, parents from the West Manjimup seed orchard (35) and the hybrid *P. attenuradiata* planted as single tree plots on a severely infested dieback site; split-plot treatment of natural and natural plus applied inoculum. An additional, control series was planted on a healthy banksia site high in the landscape. Objectives were the same as the first field test.

Advances:

* There is genetic variation on *P. radiata* to P.C. and this is strongly heritable.

* 239 plus tree selections from the Australasian breeding population have been screened for resistance to P.C. Of these 61 were classified as tolerant, 75 as moderately-tolerant, 57 as moderately-susceptible and 46 as susceptible.

* Tolerance is stable against all P.C. isolates tested so far, irrespective of whether their virulence levels are high or low. This includes an isolate of type Al.

* Results of the glasshouse screening trials have been reproduced on field trials in the Sunkland.

* Infection by P.C. leads to depressed height growth in the survivors but it has little effect on the growth of some of the tolerant families.

* Sub-lethal infections can have a major effect on the productive potential of a P.C. infested site. For example, four year-old trees of susceptible genotype 60017 were 20% taller than tolerant genotype 80007 on a dieback free Blackwood valley site, but they were 20% smaller on a Sunkland site.

* Cedros Island, Ano Nuevo and Guadalupe Island populations were generally highly susceptible to P.C. while the Cambria population was tolerant. The Monterey population, on which the Australian breeding population is based, was moderately-tolerant. Useable variation exists in each population.

* Susceptible genotypes were culled from half the West Manjimup seed orchard in 1982 to develop a P.C. tolerant seed source.

* A "specialty" (P.C. tolerant) seed orchard is to be established over the 1985-1990 period, using *Phytophthora cinnamomi* tolerant clones.

RADIATA PHASE 4: 1985-90 (commercial operations).

This phase is the culmination of the earlier phases of the tree breeding programme. Breeding values of the early plus tree selections and the imported Australasian parents have been ascertained for the W.A. environment. The interaction of the genotype with different environments has not been strong, generally the top performers have been universally good and the converse also applies. It was noted that sub-lethal infections in the Sunkland tests can have a significant effect on the genotype x environment interaction.

While considerable gains in growth rates, stem quality and branch quality have been reported earlier (Appendix 1) this has resulted from the simple mass selection. Family selection, based on our test results will give further significant benefits but large gains are still achievable from selection of the best individuals within the good families and using these as breeding trees. However to do this, complete pedigrees are required to prevent any future deterioration through related matings.

Most of the Western Australian tests of radiata pine are based on family seed lots that were open-pollinated in seed orchards. The cone parent is known but the pollin parent is not and will be drawn from only a very limited gene pool (n -50). Progeny trials have shown that parents with high general combining ability (gca) provide a larger number of outstanding offspring. Then, if selecting the best tree is an open-pollinated (orchard) family (1 in 50 or 100), there is an increasing likelihood that selections from different families may be related through a common pollinator. This will exclude any such selection from the breeding population but not from the production population, provided that the possibility of relatedness is recognised. It can be accepted by restricting the number of reselections in proportion to the various orchards genetic content and by the positioning of grafts when planting the orchard.

The best Western Australian orchard option is to maximise genetic gain through family selection and within-family selection. Our trials have provided the information for family selection but they were not designed to meet the objective of within-family selection; only some families in the International gene pool and the 1976, 1977 and 1978 tests have this. Rather than forego the added gain, some selections in the open-pollinated families have been made. Otherwise elite trees (certified plus trees) will be used in new orchards.

Another immediate option for orchard use is to make selections within specified genotypes growing in other Australian programmes. This is still being explored. If the material can be made available, there would then need to be a quarantine period to guard against Dithistroma introduction. However, direct transfer of material between South Australia and Western Australia is proposed.

In Western Australia, Phytophthora cinnamomi has a potential occurrence in all intensively managed afforestation areas. However, there are plantation sites such as the fertile loams of the river valleys and deep yellow sands on the southern coastal plain where dieback does not impose a threat. It is for this reason that two P. radiata seed sources are being developed, one to include the character of P.C. tolerance for planting on all potential P.C. infection sites and the other for planting on disease safe sites where the tolerance character need not be included in the genetic makeup.

Using seed orchards for seed propagation and tree improvement, there is a minimum lead time of some eight to ten years between tree selection and large scale seed production. With vegetative propagation selected trees can be established in the field in a much shorter time. Advantages of clonal propagation of improved material are a greater genetic gain, more rapid realisation of this gain and the development of more uniform forests than is possible with seedlings.

Forest tree breeders can effect the utility of a clone by the manipulation of the cutting donor's maturation state. For example, cuttings from more mature radiata pines typically produce trees with less volume but they develop better stem form, have fewer and smaller knots and take less time to prune compared to juvenile cuttings or seedlings. If objective is high quality timber production, then management may be willing to scarifice some per-tree volume growth for the better bole characteristics. This would not be critical on W.A. sites where agroforestry management is practised. The optimum maturation state will be a balance between the easy rooting and rapid growth rates of the juvenile age, to the declining root regeneration, improved branching habit, reduced taper and more vertical growth of the ageing state.

Production population: seed orchards

* "Specialty" (*P.C.* tolerance) orchard, 8.5 ha, P85-90. Genotypes with good expression of *P.C.* tolerance, straight stems, fine branching and vigour characters.

Clones will be represented by grafts and cuttings. A reversed - interlocking - duplicate orchard design will be used with ramets spaced at 8 x 4 m. Ramet crowns will be manipulated to facilitate efficient cone collection.

Intention is to plant the orchard over a 5 year period, establishing approximately 600 ramets each year. The genotype mix need not be the same each year; the best available genetic material at the time will be used.

Stock is available for the planting of 1 ha in 1985, using 40 clones selected from W.A. progeny trials. Genetic content is made up of:

: 23 second generation selections (genetic gain component of phenotypic + between-family + within-family selection); 6 have full pedigree, 2 were open-pollinated on ortet and 15 were open-pollinated in seed orchards (5 ex Tallaganda, 3 ex NSW and Victoria, 2 ex WA and 1 ex SA and NZ).

: 19 first generation selections (phenotpic + between-family selection).

* "General" orchard, 10 ha, P 85-90.

Genotypes with good expression of straight stems, fine branching and vigour characters. The orchard establishment plan is the same as the "specialty" orchard.

Sufficient stock is avilable for the planting of 1 ha in 1985, using 50 clones selected from WA progeny trials.

Genetic content is made up of:

: 36 second generation selections (phenotypic + between-family + within-family selection); 9 have full pedigree, 3 were open-pollinated on ortet and 24 were open-pollinated in seed orchards and clone banks (6 ex Tallaganda, 5 ex NSW, 3 ex NZ, and 2 ex WA, SA, Victoria, Queensland and South Africa).

: 14 first generation selections (phenotypic + between-family selection).

Production population: clonal propagation.

* stem cuttings - branches from selected trees in 2 - 5 year old families in progeny trials and from orchard stock plantings in the Blackwood valley.

  Annual programme of 30 000 cuttings is proposed, first stock available for P 86.

* fascicle shoot cuttings - favoured method but requires more initial development of donor cutting hedges and nursery facilities. Some created pedigree trees are available as seed but extra controlled crossings of genotypes will be required in 1985. Pedigree seed from the Australian population will be available from CSIRO and top selections from the New Zealand programme will be imported through South Australia.

Techniques for the rooting of fascicle shoots and needles are being refined at Wanneroo. The donor hedges will be developed in 1986, leading to operational propagation of 50 000 cuttings in 1987/88.

Advances:

* first clonal afforestation in 1986 of 60ha leading to 200 ha in 1988.
* first seed collection from the 1.5 to 2 generation seed orchards in 1993.

RADIATA PHASE 5: 1985→(development)

The earlier phases of this tree breeding plan are the short-term operational or utilization phases. They consist of mass-producing seed or vegetative propagules for operational planting. The result of selection is to reduce genetic variability. This is needed if gain is to be achieved. However, if selection is intensive on an initially small base, genetic variability can be eroded to an extent that it will jeopardise the long-term improvement in future generations. Care must be taken to keep a broad and flexible base in the breeding programme from which outstanding trees can be developed in the future for use in operational planting programmes.

The main conflict in tree breeding is between achieving rapid gains in the genetic quality of seed from orchards, while at the same time attempting to maintain genetic diversity. The South Australian solution to this is to gradually improve one large breeding population over repeated generations while concurrently developing from this population a more highly selected seed orchard population of individuals considered "best" by industry at that time. This strategy creates a hierarchy of populations with tree levels: (1) gene pool, (2) breeding population and (3) seed orchard population.

The Western Australian proposal is to adopt the basic principles of the South Australian plan (Cotterill, 1984) with some added simplifications to reduce generation intervals, to reduce the work load in progeny testing and have a more effective selection within families. The description of the proposed WA plan is summarised in the hierarchy of populations.

<u>Gene pool:</u>

It is proposed to conduct an intensive plus tree search in 1985 (Appendix 7). Priority areas for the search have been chosen for maximum expression of crown character. The search will be concentrated in plantations growing on high fertility sites on trees that are 25 years of age or older.

The main search will be at Nannup (600 ha) and Collie (100 ha) covering the P 56 to P 59 plantations. These plantings include six separate seed serial lots, four from South Australia and two from New Zealand. Complementary searches will be carried out at Grimwade (23 ha), Margaret River (47 ha) and Harvey Weir (105 ha), on relatively small planted areas of a greater diversity of seed origins.

Selection intensity of 1 in 1500 will be used (Burdon and Shelbourne, 1971); 600 - 800 plus trees will be selected from this search. Wood quality characters such as wood density and spiral grain will be later assessed. A minimum of 8 cones will be collected from each selection.

The WA radiata gene pool will be created by mixing an equal number of seed from all selections. This will then be raised, planted at normal spacing on a 20 ha typical afforestation site, and managed by operations. The site need not be isolated as fire protection has priority. The gene pool area will be routinely thinned leaving about 250 stems per hectare. Cones will be collected from a large number of trees (stratified random sample) at an approximate age of 25 years to perpetuate the gene pool.

Breeding population:

The success of the breeding plan depends largely on cumulative improvement of this population. Most tree breeding programmes rely on recurrent selection where superior individuals are selected from the breeding population and crossed in a particular mating pattern to regenerate a new and improved breeding population for the next generation, and so on.

The intention is to initially improve the breeding population as a single large population by selecting for traits which are most likely to remain economically important in the long-term, such as rapid growth, straight stems and fine branching. Wood density is an important trait but only needs to be maintained at its present level in the breeding population.

Because of the dieback disease, a separate breeding population may be developed when the second generation is constituted.

The first generation breeding population will comprise about 100-200 plus trees selected in earlier phases of the programme and an additional 600-700 plus trees selected from unimproved plantations in Western Australia in 1985/86.

The essence of the breeding plan is a low intensity selection among families in the first generation, followed by selection within families in successive generations of the plan. The initial family selection is intended mainly as a preliminary screening to rid the breeding population, as far as possible, of families that have an unacceptable level of malformations. The intensity of family selection (retaining 400 parents) should not be sufficient to reduce long-term gains. One phenotypically superior individual will be chosen from within each of the 400 open-pollinated (ortet) families retained and these second generation selections will be mated in single-pairs to generate a second generation breeding population of 200 unrelated full-sib families. Selection in the second and subsequent breeding populations will be entirely within families and based on individual performance. Successive breeding population sizes of 200 full-sib families will be maintained by selecting the best two trees in each family for the next single pair mating and perpetuation of the plan.

The precise statement of objectives is critical to the efficiency of the plan. There are two; the first being the determination of the breeding value of parents to a) initially screen the breeding population of poor genotypes and to b) provide a ranking of parents in successive generations for use in seed orchards and for cutting propagation. This objective can only be met in statistically designed progeny tests. The second objective is the selection within a family of the best 1 or 2 individuals to use as parents in the next cycle of the plan. Simple family block plantings will allow the most efficient selection and detailed measurement and assessment will not be necessary. Only the wood quality check of selections would be required. Detail of the progeny test and family block is given in Appendix 4.

The benefit of the plan relies on reduced generation time intervals. This will be maximised by immediately using the nine year-old selections in the family blocks for single-pair mating rather than establishing clone banks for the mating and two-stage selection proposed in the South Australian plan. Selections in the family blocks will be pollarded, thinned to a radius of 12m and heavily fertilized to stimulate flower production.

A net-merit index or complementary mating system can be used in the deliberate crossing of individuals for the next generation. Highly selected individuals can be created for certain traits, for example, the perfect agroforestry tree with desirable wood properties. These super trees can be immediately commercially propagated using fascicle cuttings.

The intention is to develop a separate population having tolerance to Phytophthora cinnamomi as a primary character. Each of the 400 selections from the first breeding population will be screened for tolerance to P.C.

A timetable of operations for the development of the breeding population is given in Appendix 5.

Major differences to the South Australian plan can be summarised as:

* definition of objectives; intensive progeny tests to define parent breeding values and large family blocks planted and maintained by operations, for efficient selection of individuals for the next generation of the plan. In the South Australian plan, all of this is done in intensive progeny tests and it is questionable if the next generation selections are really the best.

* generation interval of the WA plan is 14 years compared with a 18 year interval for the South Australian plan. This is largely due to the two-stage selection proposed in the South Australian plan and controlled pollinations being made in clone banks. The WA proposal is to shorten the generation interval by manipulating the selections in the family block and performing the pollinations on these trees.

* no two-stage selection in the WA plan. In the South Australian plan, four individuals having superior phenotypes are chosen in year 9 from each of the 200 full-sib families growing in single tree plot progeny tests. Scion material is collected to establish clone banks and open pollinated cones collected for the second stage of selection. At stage 2 of selection, the results of the open-pollinated progeny tests at year 4 are used to choose the best two parents from each set of four parents tested per family. The WA plan is to use the normal single stage selection. Cotterill (1983) expects an increase of 40% in genetic gain using the two-stage approach but this is questionable. The reselection is done at a very early age, on trees originating from a very sparce pollin cloud and on selections with an argueable base of selection intensity. Experience indicates that not all trees would have ripe cones at the age of 9 years and this could give a non-selection bias in the first selections, or the generation time interval will be further lengthened.

Production population:

The upper level of the hierarchy is the highly selected production population, which is a subset of the breeding population. Superior families in the breeding population can be cloned for use in seed orchards or for cutting propagation and thereby achieve substantial short-term gains in the plantation whilst genetic diversity is maintained over the long-term in a cumulatively improving breeding population and a large gene pool.

The production population will be supplemented by some of the outstanding families from other Australian breeding populations. This can also include material from specialized populations, for example clones with high wood density. Genotype x environment interaction for growth has been found not to be strong and inclusion of different superior genotypes should add to the potential gains. However this will be limited to 25% of the orchard content.

What size should the orchard population be? With a few highly selected clones the potential productivity of plantations will be increased but a narrow genetic base would increase the risk of plantation failure due to extremes of environment (drought) or invasions by pests or diseases. The South Australian plan will have at least 20 clones in the orchard population in each generation. We will be aiming for a minimum of 40 clones until there is information on the flowering habits of individual clones.

For clonal plantations, Libby (1980) has calculated that a safe minimum number of clones is 7 to 25 but larger numbers should be preferred. For example, in a Norway spruce programme in Germany 50 to 100 clones are being planted in a random mixture (Kleinschmit and Schmidt, 1977).

If the timetable for the breeding plan is followed it will take 10 years until the progeny tests are assessed to evaluate breeding values. Superior selections from the family blocks could be used as cuttings to establish a new series of orchards twelve years from now, in 1997. Single-pair matings of superior selections for the second generation population could be used for clonal propagation with first cuttings available from 2001.

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Appendix 1: Results from W.A. *Pinus radiata* progeny and yield trials.

1. Character: Diameter (bhob in cm).

Progeny trial	routine	pedigree	difference	top quartile*
RS.1(1969) age 8	12.8	13.2	+3%	14.0
RS.2(1971) age 7	17.7	18.6	+5%	19.6
RS.3(1971)	16.7	17.9	+7%	19.0
RS.4(1972)	15.4	15.8	+3%	16.7
RS.5(1972)	13.8	13.6	-1%	14.8
RS.8(1974) age 10	12.3	13.8	+12%	14.5
Yield trial				
RX.1(1973) age 6	16.0	16.6	+4%	
RX.2(1973) age 7	11.6	12.0	+3%	
r/o (1974) age 10	12.3	13.2	+7%	

* average for the top ranking 25% of families in the trial.

2. Character: Height (m).

Progeny trial	routine	pedigree	difference	top quartile
RS.1(1969)	2.2	2.1	-5%	
RS.2(1971)	7.5	7.5	=	8.1
RS.3(1971)	3.1	3.5	+11%	3.8
RS.4(1972)	5.9	5.9	=	6.3
RS.8(1974)	3.8	4.2	+11%	4.5
Yield trial				
RX.3(1973) age 4	4.2	4.4	+5%	
r/o (1974) age 4	3.8	3.8	+1%	

3. Character: Stem straightness (% of trees in trial that are straight).

Progeny trial	routine	pedigree	difference	top quartile
RS.1(1969)	2.39*	2.59	+8%	2.79
RS.2(1971)	52	58	+12%	70
RS.3(1971)	76(12**)	83(22)	+10%(+83%)	91(34)
RS.4(1972)	33	41	+24%	64
RS.8(1974)	32	63	+97%	72

Appendix 1 (continued).

Yield trial				
RX.1(1973)	49	52	+6%	
r/o (1974)	32	64	+100%	

* mean point score

** % of trees in trial that are very straight

4. Character: branch thickness (% of trees in trial with thin branches).

Progeny trial	routine	pedigree	difference	top quartile
RS.1(1969)	2.57*	2.67	+4%	2.92
RS.2(1971)	44	59	+34%	70
RS.3(1971)	71(8**)	85(23)	+20%(+200%)	95(38)
RS.4(1972)	36	69	+92%	88
RS.8(1974)	30	49	+63%	63
Yield trial				
RX.1(1973)	87	88	=	
r/o (1974)	30	42	+40%	

* mean point score

** % of trees in trial with very small branches.

5. Character: branch angle (% of trees in trial with flat angle branches).

Progeny trial	routine	pedigree	difference	top quartile
RS.1(1969)	2.82*	2.83	+1%	3.1
RS.2(1971)	50	56	+12%	69
RS.3(1971)	85(15**)	89(27)	+4%	97(41)
RS.4(1972)	56	80	+43%	94
RS.8(1974)	52	66	+27%	75
Yield trial				
RX.1(1973)	26	29	+12%	
r/o (1974)	52	58	+12%	

* mean point score

** % of trees in trial with right angle branching.

Appendix 2: Breeding values of clones in W.A. tests.

(a) some clones with high gca.

P. radiata clone	Height	Diameter	Stem Straightness	Branch Thickness	Branch Angle	P.c. tolerance	Wood Density
12038	**	**	***	**	**	***	**
12349	**	**	**	**	***	***	*
12374	*	**	**	**	***	*	*
10957	**	***	*	**	-		**
10956	**	*	**	*	*	**	*
12112	*	-	*	**	**	--	-
12130	*	*	**	**	**	**	*
30002	-	*	***	**	*	*	-
30007	-	*	*	**	**	--	*
30011	**	-	***	***	**	*	
30012	***	***	***	***	-	-	
30016	***	**	*	-	-	--	*
30026	**	**	*	*	--	**	*
50001	***	**	***	**	*	-	*
50006	**	*	***	-	***	*	*
50012	***	***	**	*	*	--	**
50048	***	***	**	*	***	--	
50015	***	***	*	*	***	-	*
50266	*	*	***	***	**	-	
50269	***	***	***	**	--	--	-
60004	**	**	**	**	-	-	
60015	**	**	*	*	-	*	
60002	**	*	-	*	**	**	
70052	***	***	***	***	***	--	
70053	*	**	*	**	***	*	
80007	*	*	**	**	***	***	***
80055	**	**	*	*	**	--	--

Appendix 2 (continued).

(b) some clones with poor gca.

P. radiata clone	Height	Diameter	Stem Straightness	Branch Thickness	Branch Angle	P.c. Tolerance	Wood Density
12236	***	*	--	--	**	--	-
12001	-	-	--	-	-	-	
12197	-	*	*	-	-	-	*
12247	-	-	--	*	-	-	*
12378	-	--	*	*	**	-	--
12408	*	-	-	*	*	-	--
30004	*	*	--	--	-	--	*
30017	--	--	-	--	-	*	**
30036	--	--	*	*	--	**	
30040	-	--	*	-	--	**	**
30043	-	-	-	--	-	**	*
30048	-	-	--	-	--	-	-
50024	*	-	--	--	-	*	**
60001	*	-	-	-	-	--	
60003	-	-	-	-	--	*	
60017	***	***	*	--	-	--	

Breeding value code:

*** very high
** high
* average
- low
-- very low

Appendix 3: Schedule of seed orchard populations.

Year	Phase 2 W.M.S.O.		Phase 4 "General"		Phase 4 Specialty		Phase 5 2 gen.		Phase 5 3 gen.	
	Age	Yield	Age	Yield	Age	Yield	Gen.	Spec.	Gen.	Spec.
1982	11	205kg								
1983	12	327								
1984	13	310								
1985	14	200	plant		plant					
1986	15	160	plant		plant					
1987	16	200	plant		plant					
1988	17	200	plant		plant					
1989	18	250	plant		plant					
1990	19	250								
1991	20	250								
1992	21	250								
1993	22	250	6	60kg	6	50kg				
1994	23	250	7	100	7	80				
1995	24	250	8	150	8	130				
1996			9	150	9	130				
1997			10	180	10	150	plant			
1998			11	180	11	150	plant			
1999			12	180	12	150	plant			
2000			13	180	13	150	plant	plant		
2001			14	180	14	150		plant		
2002			15	180	15	150		plant		
2003			16	180	16	150				
2004			17	180	17	150	70kg			
2005			18	180	18	150	110			
2006			19	180	19	150	160	50kg		
2007			20	180	20	150	170	80		
2008			21	180	21	150	200	80		
2009			CF		22	150	200	130		
2010							200	130		
2011							200	150	plant	
2012							200	150	plant	
2013							200	150	plant	plant
2014							200	150	plant	plant
2015							200	150		plant

Appendix 4: Progeny test and family block features of the breeding plan.

PROGENY TEST

* objective - to define breeding values of parents.
* information - (a) screen initial selections for parents to go into the breeding population.
  (b) provide a ranking of parents for use in seed orchards and cutting propagation.
* design - incomplete block, 30-50 individuals in each family planted in single tree plots.
* repeat on principal planting sites.
* standard management prescriptions.
* measure - height at 4 years, diameter, height, tree form and wood quality at 9 years.
* conversion to seedling seed orchard after 9 years.
* isolation not necessary, maximum fire protection essential.

FAMILY BLOCK

* objective - selection of phenotypically superior individuals within a family planting.
* design - single families will be planted in compact blocks of 100-200 seedlings to facilitate selection of the best individuals in family groups.
* repeat on principal planting sites.
* standard management prescriptions.
* no measurements will be carried out.
* phenotypically superior individuals within a family will be selected at age 9 years. Evaluate wood properties, collect scions for establishment in clone bank and pollen for single-pair mating.
* release selected trees by removing adjacent trees to a distance of 12 m, pollard selected tree and apply fertiliser and hormone treatments to stimulate flower production.

Appendix 4 (continued).

* single-pair mating of selected trees will be performed in the family block to decrease the time interval between generations.

Appendix 5: Timetable of operations in Phase 5.

Year 0 (1985):	SEARCH 1985, search 700 ha of plantation type 1 for 700 plus trees.
:	Plus tree classification and wood properties.
:	Collect 8 cones/ortet, scions for grafting and establishment of clone bank.
Year 1 (1986):	Sow family seed lots in nursery.
:	Mix some seed from each family to create the gene pool and sow in nursery.
Year 2 (1987):	Plant the 1st generation breeding population in progeny tests and family blocks at two or three major plantation sites.
:	Plant the gene pool.
Year 6 (1991):	Progeny test - measure heights.
Year 11 (1996):	Progeny test - measure heights, diameter and wood quality, assess tree and branching form. Rank all parents on these characters and select the best 400 parents to use in the breeding population. Develop progeny test as a seedling seed orchard.
:	Family block - in the chosen 400 families, select the phenotypically superior individual for each of the 400 families. Collect scions for cutting propagation and establishment of clone banks and collect pollen. Release selected trees and treat to stimulate flowering. Use cuttings of the best 40 clones to plant in seed orchards.
:	Clone bank - collect open-pollinated seed of the 400 chosen parents, raise seedlings and carry out glasshouse screening tests for <u>Phytophthora cinnamomi</u> tolerance.
:	Establish a yield trial.

Appendix 5 (continued).

Year 12 (1997): General seed orchard (11 ha) - plant cuttings of the best 50 second generation selections, 3 ha a year for 4 years. This orchard will be developed at the West Manjimup Forestry Centre.

: Family block - single-pair mating of the 400 chosen clones to create 200 unrelated families.

Year 14 (1999): Family block - collect control pollinated seed.

Year 15 (2000): Sow family seed lots in the nursery.

: General seed orchard, final planting of 3 ha.

: Specialty seed orchard (8.5 ha) - plant cuttings of P.c. tolerant seedlings over 3 years. This orchard will be developed on part of the original West Manjimup seed orchard site (clearfelled in 1998).

Year 16 (2001): Plant the 2nd generation breeding population in progeny tests and family blocks at two or three major plantation sites.

: Phytophthora cinnamomi tolerant population - complete the ranking of the chosen families for P.c. tolerance and recommend a strategy for the development of this population.

: Fascicle shoot propagation of outstanding families for clonal afforestation.

Year 20 (2005): Progeny test - measure heights.

: Establish a yield trial.

Year 25 (2010): Progeny test - measure heights, diameter and wood quality, assess tree and crown form. Rank breeding values of parents for use in seed orchards and clonal propagation. Develop as a seedling seed orchard.

Appendix 5 (continued).

: Family block - select two phenotypically superior individuals in each family (200 x 2 = 400). Collect scions for cutting propagation and establishment of clone banks, and collect pollen. Release selected trees and treat to stimulate flowering. Use cuttings from the best 40 clones to plant in seed orchards.

Year 26 (2011): General seed orchard (10 ha) - plant cuttings of the best 50 third generation selections, 3 ha a year for 4 years. This orchard will be developed on the Manjimup general orchard site planted 1985-90 (clearfelled 2009).

: Family block - single-pair mating of the 400 selections to create 200 new families.

: Gene pool - collect cones at random from a large number of trees (planted in 1987), mix seed to regenerate and form the new gene pool.

Year 28 (2013): Family block - collect control pollinated seed.

: Gene pool - plant the gene pool.

: Specialty seed orchard (8.5 ha) - plant cuttings of the best third generation selections, 3 ha a year for 3 years. This orchard will be developed on the specialty orchard site planted 1985-89 (clearfelled 2011).

Year 29 (2014): Sow family seed lots in the nursery.

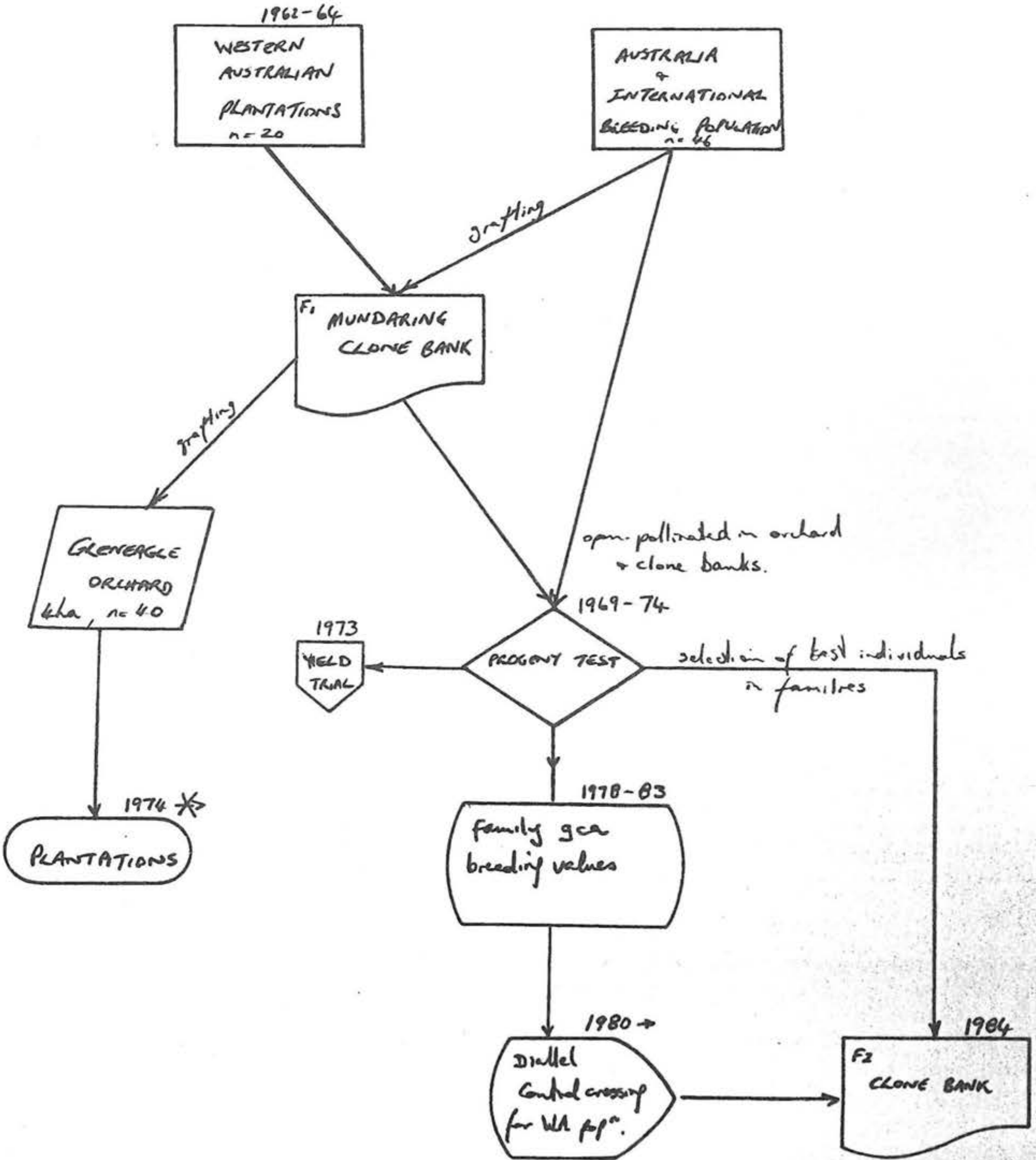
: General seed orchard, final planting of 3 ha.

Year 30 (2015): Plant the 3rd generation breeding population in progeny tests and family blocks at two or three major plantation sites.

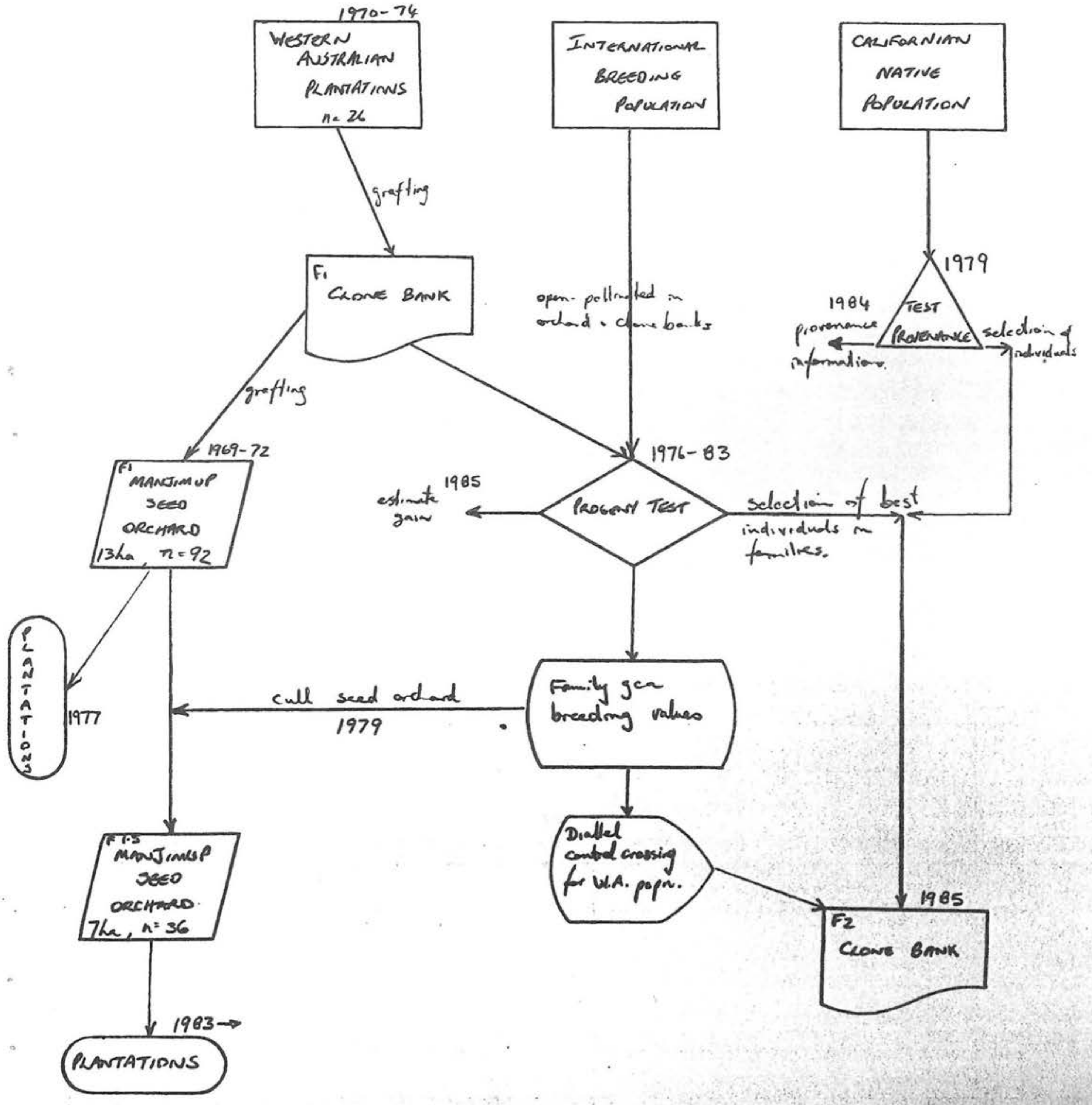
: Fascicle shoot propagation of outstanding families in this population for clonal afforestation.

Appendix 6.

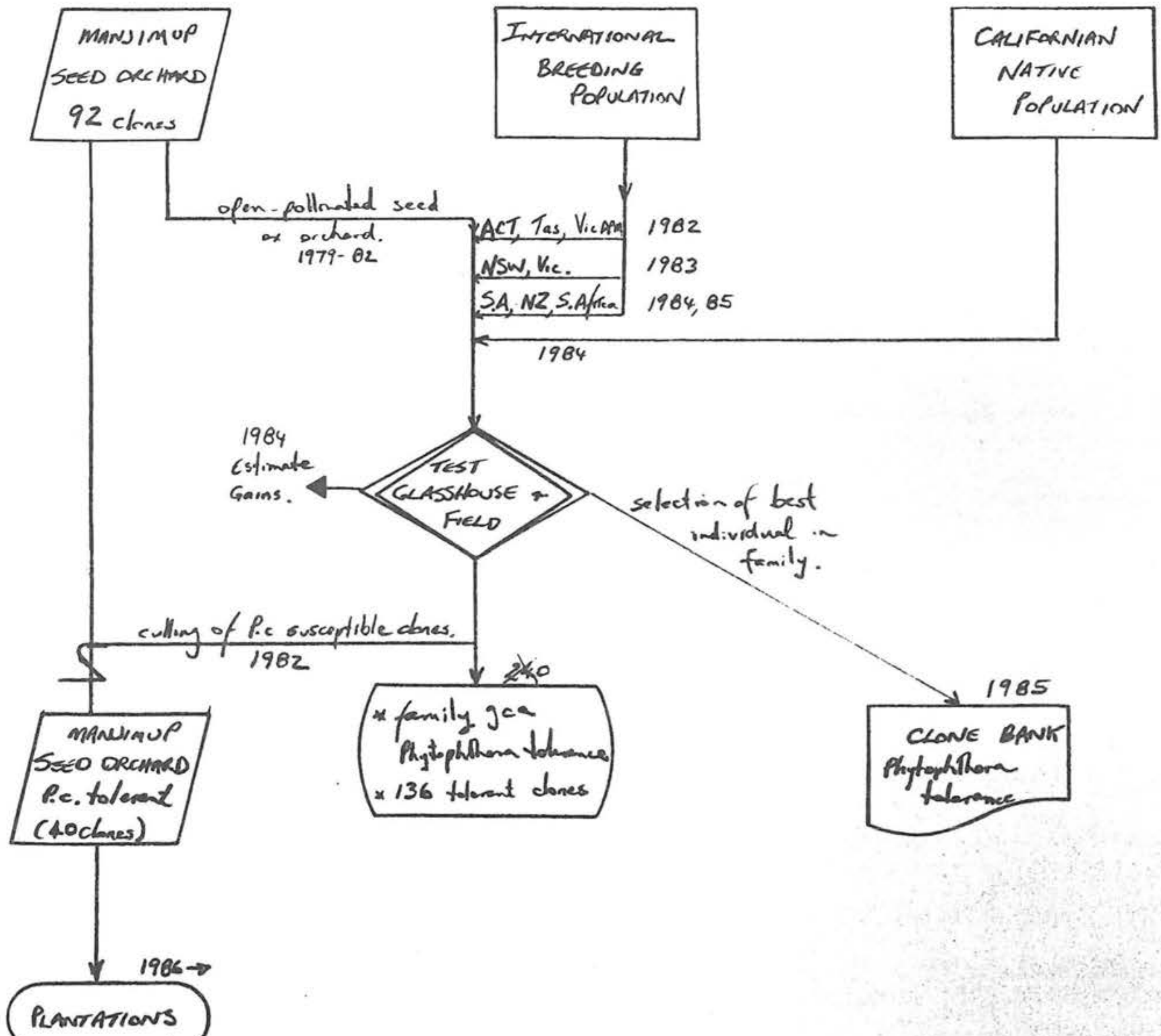
RADIATA PHASE I : 1960 – 1970 (Commencement)



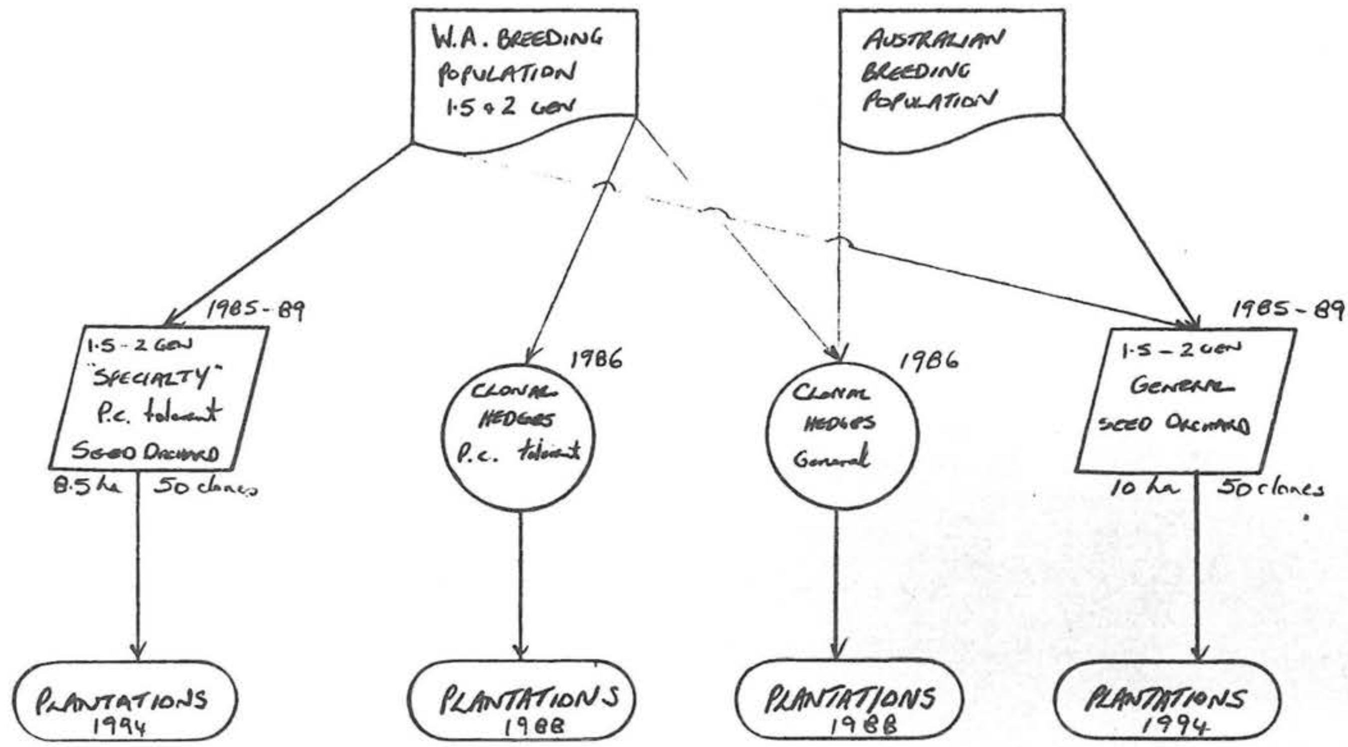
RADIATA · PHASE 2 : 1970 – 1980 (enrichment)



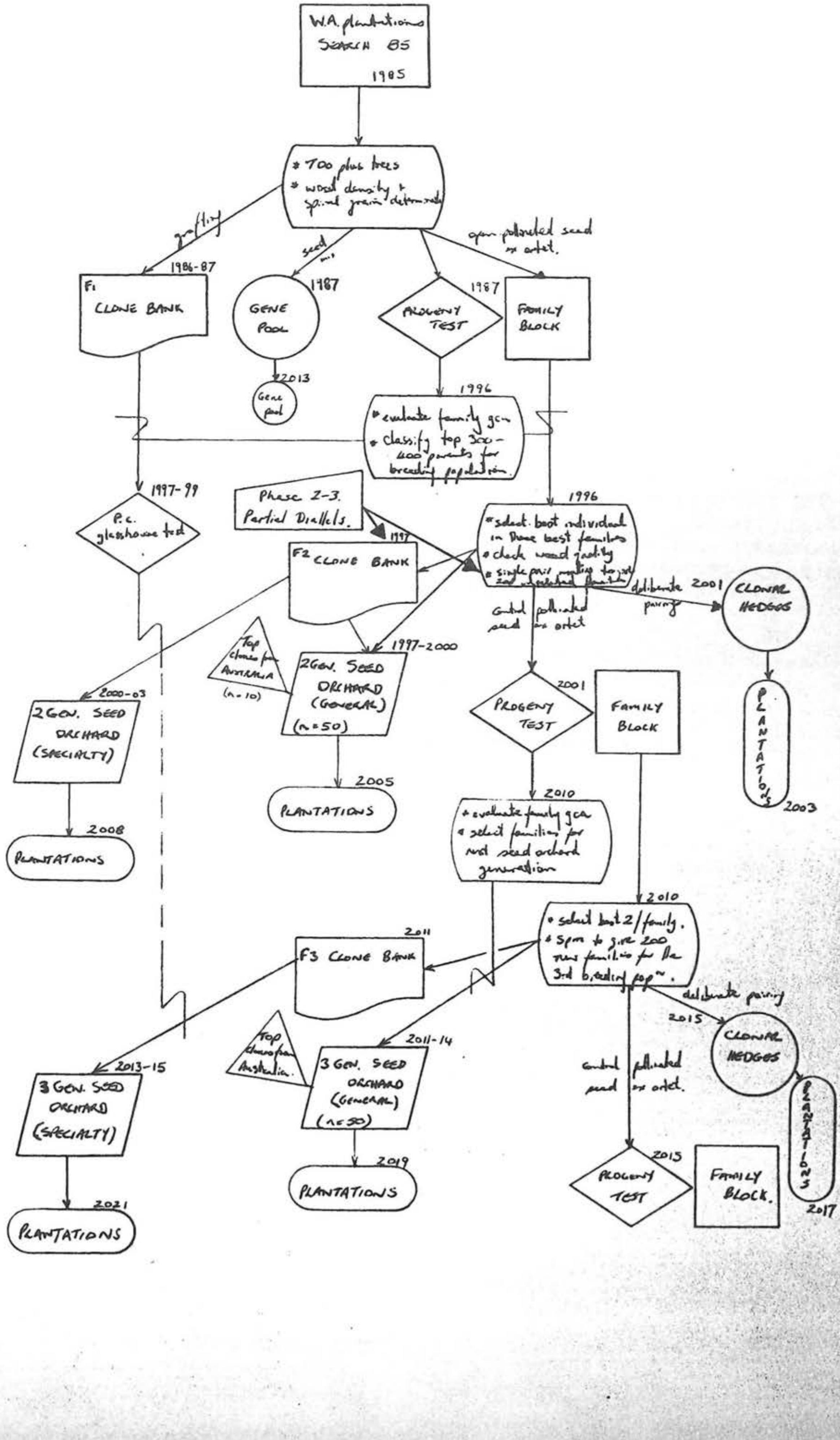
RADIATA PHASE 3 : 1980-1985 (*Phytophthora cinnamomi* disease resistance)



RADIATA PHASE 4 : 1985-1990 (Commercial operations)



RADIATA PHASE 5 : 1985 → (Development)



A/CONSERVATOR OF FORESTS
STATE HEADQUARTERS

H.O. 400/65
Loc. 6/3

PINUS RADIATA PLUS TREE SELECTION

Plus tree selection in Pinus radiata plantations in Western Australia has been spasmodic, non-systematic and poorly co-ordinated in the past. The result of this is the meagre total of 47 WA plus trees in our breeding population. This number is a totally inadequate base for the future improvement of P. radiata in this state. Large gains have already been shown from our programme but these are minor compared to the future gains possible from the crossing and propagation of highly select genotypes.

It is essential that the base breeding population of Pinus radiata in Western Australia is expanded immediately.

It is proposed to conduct an intensive plus tree search in 1985. The priority is for "agroforestry" plus trees, trees that are straight with small limbed, deep crowns. The 1985 search will be concentrated in plantations growing on high fertility sites on trees that are 25 years of age or older. Selection intensities of 1 plus tree per hectare (SI, 1:1000-2000 trees) will be used. The proposal is to search 600 ha in Folly/Milwards plantation at Nannup and 100 ha in the Mungalup plantation; 600 plus trees will be selected from this search.

District Forester Ray Fremlin and Forester Gordon Chester will co-ordinate and implement this proposal. The initial selection work will take 70 man days which is beyond the capacity of technical staff. As this project is of vital concern to the Central Region, the region could provide 4 recent forestry cadets for three weeks based at Nannup to assist in the plus tree selection. Failing Central Region support, this selection will need to be carried out over a 2 year period.

Appendices to this proposal include:

1. W.A. Plantation site types for selection.
2. Intensity of selection.
3. Pinus radiata plus tree selection traits, notes for searchers.
4. Plus tree classification.
5. Method of plus tree selection.
6. P.O.C.S sheets for the 1985 search.

T.B. BUTCHER
S.D.F.O.

TBB:KC
Como Research
3 December 1984

Attention: Mr Havel
Mr Underwood
Mr Van Noort

Attach.

1. PLANTATION SITE TYPES FOR SELECTION

Pinus radiata plantations in Western Australia can be divided into:

1. River valley - high fertility sites
   (a) former pasture
   (b) former bushland
2. Coastal plain sands - low fertility site.
3. Donnybrook sunkland - infertile, poor drainage, shallow soils and dieback infested.

Twenty year and older plantation areas are tabled:

Plantation	Group	P year	Area	Type
Nannup	Folly	1956-1963	734 ha	1a
	Lewana	1961-1965	387 ha	1a
	Milward	1957-1965	498 ha	1a
Kirup	Grimwade	1933-1960	689 ha	1b
	Grimwade	1961-1965	549 ha	1b
	Ferndale	1962	5 ha	1a
	Kelly	1965	50 ha	1b
Collie	Mungalup	1957-1961	260 ha	1a & 1b
	Bussells	1957-1965	428 ha	1b
	Wellington	1960-1962	118 ha	1b
Harvey	Harvey Weir	1939-1963	186 ha	1b
	Brunswick	1959-1964	149 ha	1b
	Myalup	1930-1965	100 ha	2
	McLarty	1953-1965	38 ha	2
	Tallanalla	1955-1965	205 ha	
Busselton	Margaret	1933-1957	64 ha	1b
	Ludlow	1910-1965	79 ha	2
Mundaring	Greystones	1922-1960	28 ha	1a
	Helena	1923-1965	30 ha	1a
	Gorrie	1959-1963	117 ha	
	Beraking	1931-1965	210 ha	
	Wellbucket	1953-1965	68 ha	
	Cliffords	1957-1965	24 ha	
	Carinyah	1925-1965	16 ha	

The 1985 search will concentrate on the plantations:

Nannup	Folly	P56	116 ha
	Folly	P57	92 ha
	Milward	P58	166 ha
	Milward	P59	247 ha
Collie	Mungalup	P57	75 ha
	Mungalup	P58	86 ha

These are the base populations; they can be searched to locate the best adapted trees for the particular site type. "Plus" trees are selected for their distinct superiority to the average of neighbouring trees; they are phenotypes (interaction of environment with genotype). Heritability of the character will determine how closely the phenotype resembles the genotype.

heritability	character
high	branching type
"	*Phytophthora cinnamomi* tolerance
intermediate	stem straightness
"	height
"	branch quality
"	diameter
"	wood density
low	forking and ramicorn branches

Plus trees are the foundation of the tree breeding programme; they are the building blocks that start the pedigreed lines of selection over future generations. The base breeding population must be very broad to allow for selection of an increasing number of characters, present and future.

2. INTENSITY OF SELECTION

Selection standards for plus trees were set very high for all breeding programmes when initiated in the late 1950s; large areas were searched for very few outstanding plus trees on the assumption that heritability and additive genetic variance would be fairly high for all characters. Now that some preliminary estimates of heritability are available the tree breeders reliance on intensive phenotypic selection has decreased.

The Pimelia plantation plus tree selection carried out by Butcher, Fremlin and Kruger in 1970 can be used as an example. The 125 ha of 36-42 year old *P. radiata* were cruised on a 100 m grid, resulting in:

initial search = 74 trees; SI, 1:3800.
candidate plus trees = 21 ; SI, 1:13000.
plus trees = 5 ; SI, 1:56000.

Of the 5 plus trees selected for the breeding population, only 1 appears to be good in all characters viz. stem straightness, branching quality, vigour and *Phytophthora* tolerance. It is obvious now that all of the 21 candidate plus trees (SI,1:13000) if not the 74 trees from the initial cruise should have been included in the initial breeding population and progeny testing then would have revealed more trees suitable for inclusion in the breeding population. The breeding population requires large numbers of genotypes to carry through future generation cycles that promise very large gains in productivity.

Selection intensity of 1 plus tree per hectare or 1:1000 to 2000 trees will be used in the 1985 selection series.

3. PINUS RADIATA PLUS TREE SELECTION TRAITS

W.A.:1985 series, notes for searchers

1. STEM FORM:

   * The tree must be straight. The stem should have no bends or lean and it should be circular in cross-section. Slight bends can be only accepted if the tree is better than its neighbours.

2. BRANCH QUALITY:

   * Multi-nodal trees with regular spaced, small diameter, short length, flat angled branches. There should be 2-3 branch whorls per year, preferably at an even distance apart. Avoid trees with long branches; in wide spaced plantations, a tree with short branches is particularly desirable. Branches coming out at right angles to the stem are ideal; avoid trees with very steep angled branches.

3. TREE VIGOUR:

   * The tree must be at least as tall as the biggest tree in the immediate vicinity. Preferably, it should also be as big (diameter) as the biggest tree.

4. TREE HEALTH:

   * Crowns should be dense, healthy and vigorous; avoid thin crowns of light green needles, any signs of dead topping or rusty crowns. Avoid any stems exuding resin or showing signs of insect attack.

5. STEM CONES:

   * Avoid trees with large numbers of cones on the stem.

Candidate plus trees should be good in all characteristics and possibly outstanding in one or two. Trees inferior in an important character should not be selected.

Each candidate plus tree will be tested for wood quality, principally basic density and grain angle. The acceptance standards will be set after the population values have been determined.

4. PLUS TREE CLASSIFICATION

Following the initial search and location of candidate plus trees, quantification of the phenotypic values and classification of the trees is necessary. This is done by the comparison tree method. Nine other crop trees (rate 250 s.p.h.a) in the immediate vicinity of the candidate plus tree and occupying similar site conditions, are chosen. This discrete group of ten trees forms the micro-site population; candidate plus tree characteristics are rated against this to determine superiority.

Characteristic to be rated as:

1 =	*superior*	(better than 2 standard deviations from the mean or the best of 10 trees).
2 =	*better than average*	(between 1 and 2 Std. Dev. from the mean or the best or second best of 10 trees).
3 =	*average*	(within 1 Std. Dev. from mean, or intermediate).
4 =	*below average*	(between -1 and -2 Std. Dev. from the mean, or last or second last of 10 trees).
5 =	*very poor*	(more than -2 Std. Dev. from the mean, or poorest of 10 trees).

External characteristics - measured

Diameter:

* measure diameter over bark at height of 1.3 m.

Height (tree):

* measure height of tree using clinometer.

Height (crown):

* measure height of first green crown whorl; calculate green crown length.

Crown width:

* measure crown width (diameter) along row and across row (bay); calculate crown area and the ratio of crown area/stem area.

Tree volume:

* calculate Dbhub = 0.506 + 0.862 Dbhob cm.
* calculate Vol.ub = 0.472 Dbhub^2 x Ht m^3.

External characteristics - visual assessment

Stem straightness:

1 - perfectly straight.
2 - straight, very slight deviation.
3 - straight, with slight deviations.
4 - reasonably straight, obvious deviations.
5 - not straight, marked kinks, sweeps or lean.
6 - crooked, extreme deviation.

Branch type (3 to 10 m above ground):

1 - uni-nodal.
2 - bi-nodal.
3 - multi-nodal.

Branch thickness and length (to be related to tree vigour):

1 - very small, short branches.
2 - small, short branches.
3 - acceptable, average diameter and length of branches.
4 - moderate, slightly larger and long branches.
5 - large diameter, long branches.
6 - very large diameter, long branches.

Branch angle:

1 - very flat, right angles to stem.
2 - flat angle, 70-80^o to stem.
3 - low angle, 60-70^o to stem.
4 - moderate angle, 50-60^o to stem.
5 - high angle, 40-50^o to stem.
6 - very steep angled, $<40^o$ to stem.

Tree form:

1 - normal
2 - ramicorn
3 - fork
4 - multiple or repeated forking.

Tree health:

1 - dark green, dense, healthy crown.
2 - dark green, healthy crown.
3 - dark green, sparce crown.
4 - light green, sparce crown.
5 - dead topping.
6 - rusty crown.
7 - resinous stem.

Stem cones:

1 - trunk cones cast shortly after maturity.
2 - scattered persistent trunk cones.
3 - numerous persistent trunk cones.

5. METHOD OF PLUS TREE SELECTION

1. OFFICE

* Collect the plantation maps.
* P.O.C.S. sheet for the particular age class.
* Aerial photographs - flight age 6-7 years to show extraction tracks, compartment cross breaks etc. May be able to use most recent photographs as well.
* Photocopy aerial photographs and draw up a 200 m x 200 m grid system; index the grid with compartment number and grid unit number. These selection units will be 4-5 ha in area.

2. FIELD

* Staff undertaking this work should be specifically trained for the job.
* Mark out the end of the 200 m row to delineate the selection unit, using yellow plastic ribbon (need to mark the 6 trees at the end of each of the runs). Do this for all units. It is only necessary to mark trees if the breaks and tracks are not discernible in the field.
* Working in teams of two assessors, traverse the selection grid as illustrated in diagram. Each assessor looks towards the other through 16 rows of trees. Either walk through or use horses; each assessor has radio communication. Search for trees that have the specified characters; mark any worthwhile tree in the first run, using white plastic ribbon. At the end of each unit, several trees will have been marked; these are then closely scrutinised by both assessors and the best <u>4</u> trees selected are marked with an additional white plastic ribbon; these are then located with reference to the compartment boundary for permanent marking and referencing. Of the 4 selected trees/unit, a ranking of the <u>best 1</u> and <u>2</u> trees should be given.
* Cover the plantation group specified.

3. OFFICE

* Collate all data from the initial plus tree cruise.
* Allocate plus tree candidate numbers to each of these trees. Note that these are not the plus tree numbers, these will only be allocated after the candidate trees have (a) scored for external characters (b) screened for wood properties (c) cones collected from.

4. FIELD

* Do the candidate plus tree external character assessment on the standard form. Compare candidate tree with population crop trees (10 in closest proximity in 250 spha stand).
* Take wood core for spiral grain and wood density determination.
* Determine wood properties of candidate. Decision then as to if to accept as a plus tree.

* Using rifle, collect minimum of 8 cones/plus tree; in each compartment where plus trees were collected randomly choose two other trees and collect 8 cones/tree to represent the bulk average population.
* Take photographs (3) of each plus tree to show bole, crown and total tree.
* Using rifle, in July/August collect scion material for grafting and establishment of clone banks.
* If 'plus' trees were not carrying cones, return in the following years to complete the cone collection.

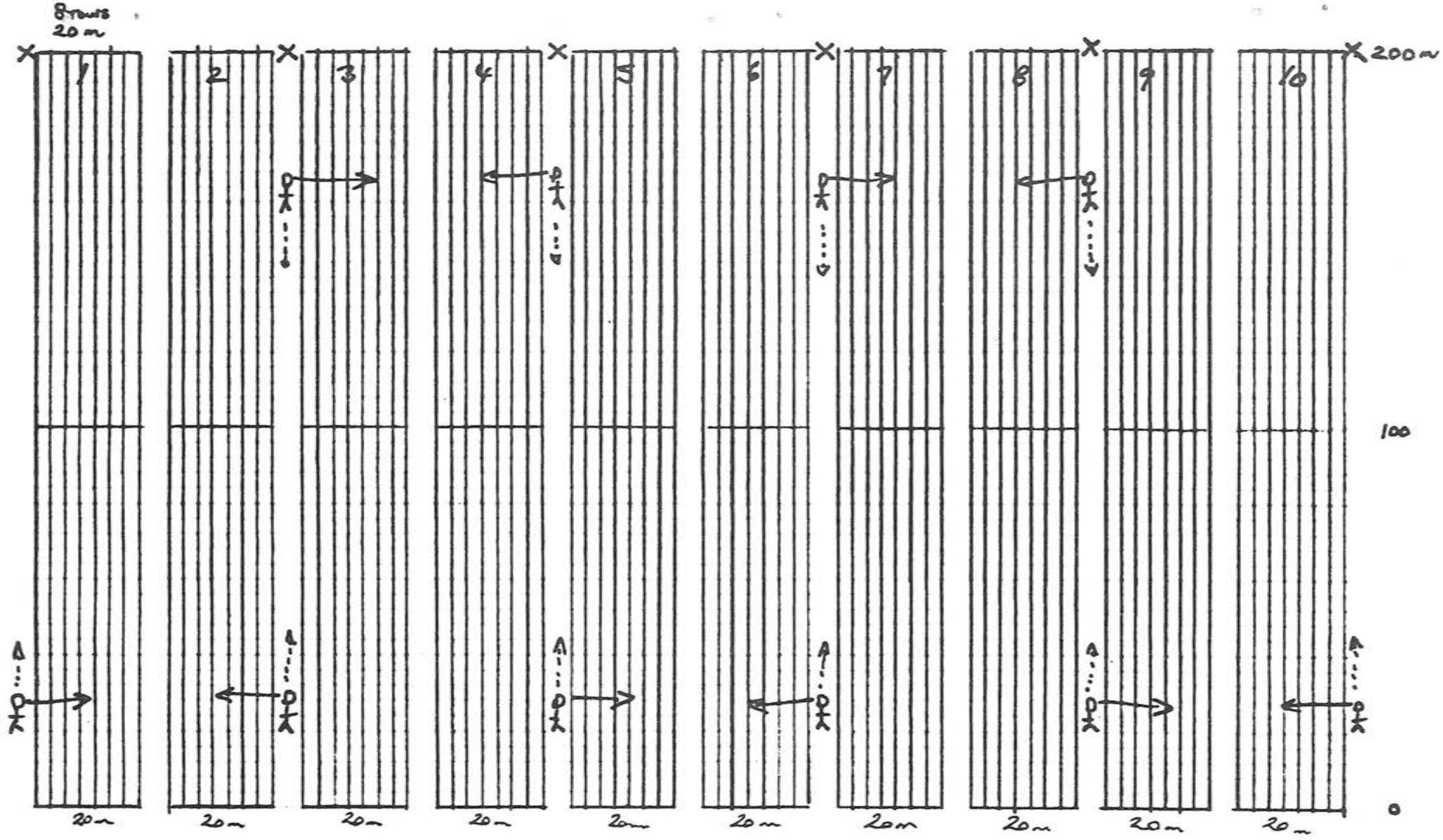
5. OFFICE

* Calculate phenotypic values for each of the traits and rank plus trees for potential immediate use; top ranked trees to go into general seed orchard.
* Register plus trees on plantation plus tree map; register plus trees on P.O.C.S.
* Design comprehensive progeny tests and arrange for co-operative trials. Implement these screening tests as soon as possible. The definitive statement of progeny test objective is extremely important.

6. FIELD

* Establish clone bank for all plus trees.
* Introduce the best of the plus trees into the general seed orchard.
* Raise progeny and plant the op progeny test and the family blocks on 2 representative sites.

7. CONTINUE THE SELECTION PROCESS TO EXPAND THE BASE BREEDING POPULATION.



Plus Tree Selection Unit of 4 ha

Foley planting spacing 2.4 x 2.4 m $\xrightarrow{90\%}$ 1500 sph.

Selection intensity of 1 : 1500 mark 4 trees

1 : 2000 mark 3 trees

1 : 6000 best tree.

Milwards planting spacing 2.7 x 2.7 m $\xrightarrow{90\%}$ 1250 sph

Selection intensity of 1 : 1250 mark 4 trees

1 : 1670 mark 3 trees

1 : 5000 best tree.

WESTERN AUSTRALIAN PLUS TREE CLASSIFICATION

SPECIES	PLANTATION	GROUP	SECTION AND COMPARTMENT	P. YEAR	S.N.	DATE	AGE

PLUS TREE COORDINATES (FROM SE CORNER OF COMPARTMENT) →W: m. →N m.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

CHARACTERISTICS

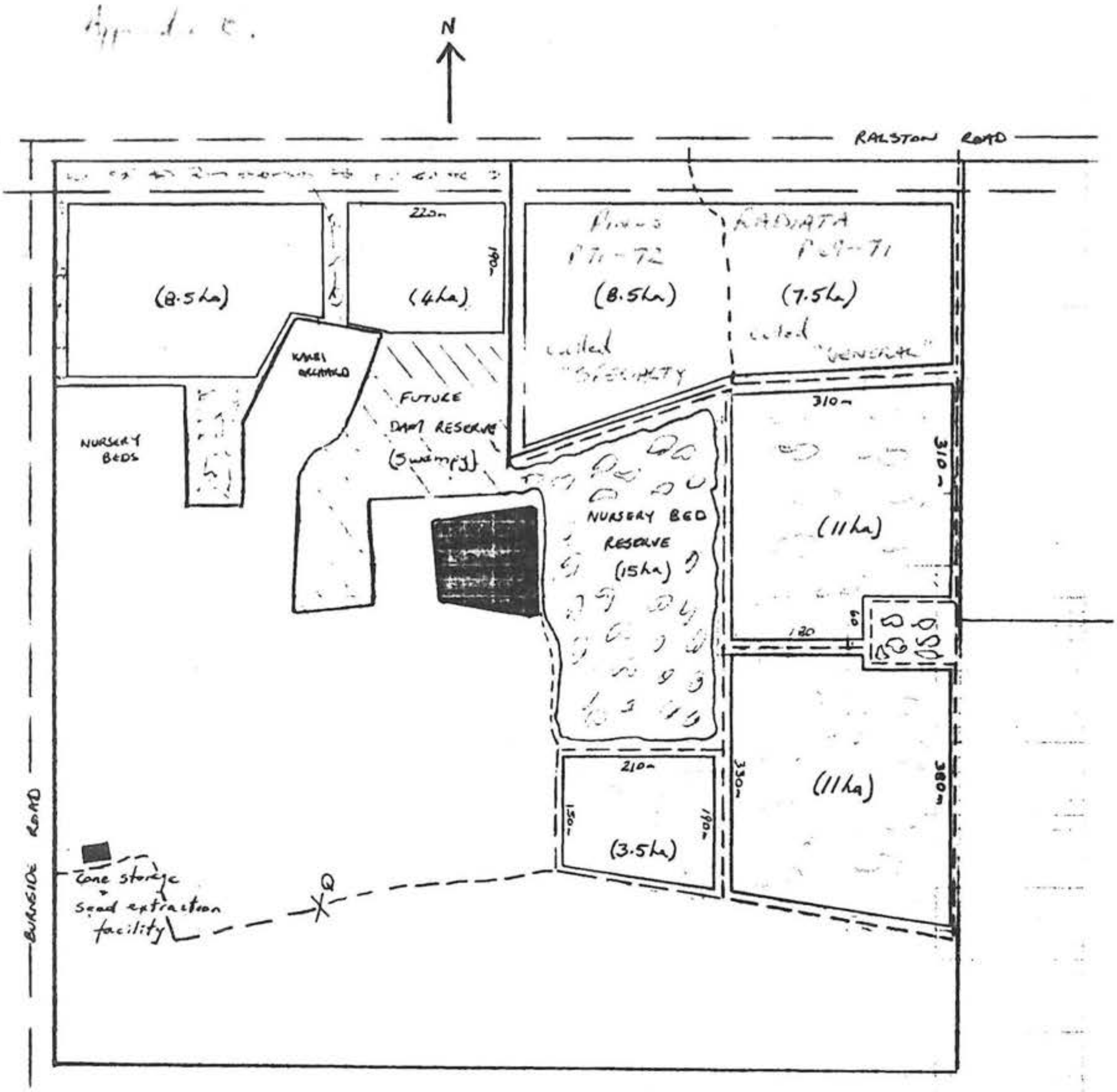
CANDIDATE PLUS TREE		EXTERNAL															INTERNAL		
		DIAMETER	HEIGHT		GREEN	CROWN WIDTH		AREA	VOLUME	STRAIGHTNESS	BRANCH TYPE	B. THICK. & LENGTH	BRANCH ANGLE	TREE FORM	HEALTH	STEM CONES	WOOD	SPIRAL	FIBRE
		BHOB	TREE	CROWN	CROWN	ROW	BAY	CROWN/	TREE								DENSITY	GRAIN	LENGTH
		cm	m	m	LENGTH	m	m	STEM	m^3								$g.cm^{-3}$		mm
Popn.	2																		
	3																		
	4																		
	5																		
	6																		
	7																		
	8																		
	9																		
	10																		
MEAN																			
STD.DEV.																			
S.DIFF.																			

SELECTION INTENSITY:

SITE DESCRIPTION: (s.p.ha)

TREE DESCRIPTION:

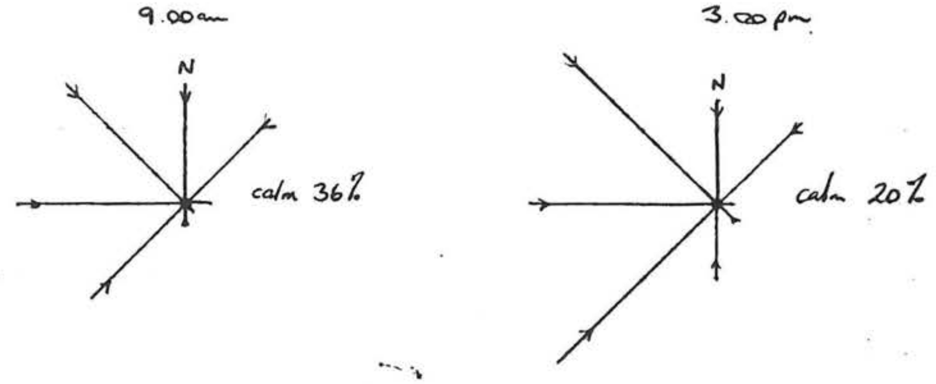
Appendix C.



SCALE (APPROX) 1 cm = 84 m.

WIND DIRECTION AT MANJIMUP (1957–61)

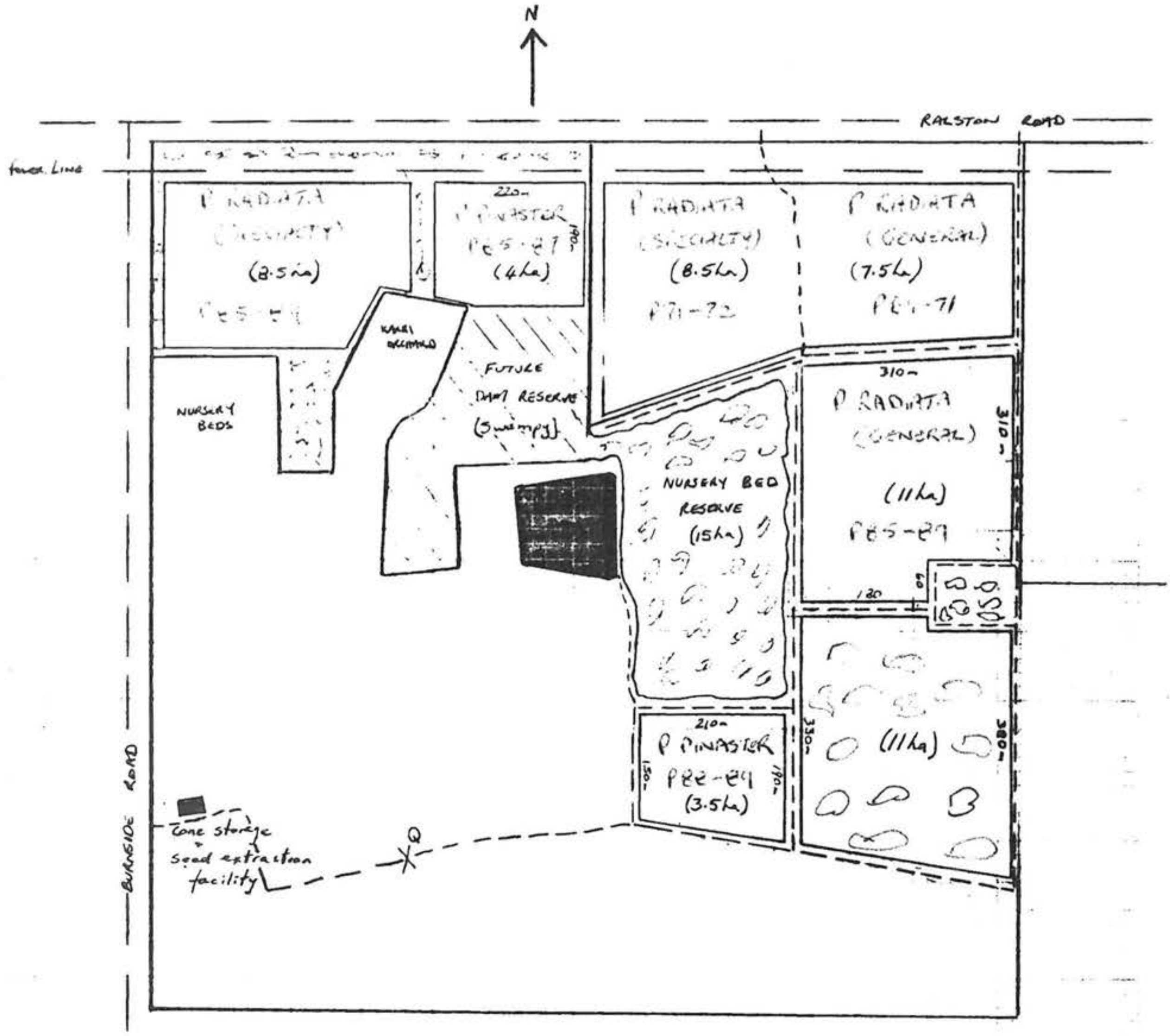
AUGUST PERCENTAGE FREQUENCY



WEST MANJIMUP FORESTRY CENTRE

PINE SEED ORCHARDS

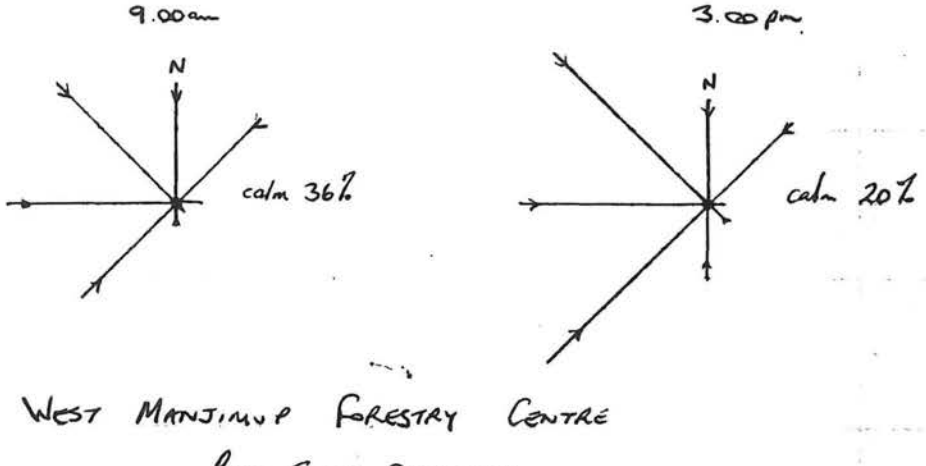
I – as at 1984



SCALE (APPROX) 1cm = 84m.

WIND DIRECTION AT MANJIMUP (1957–61)

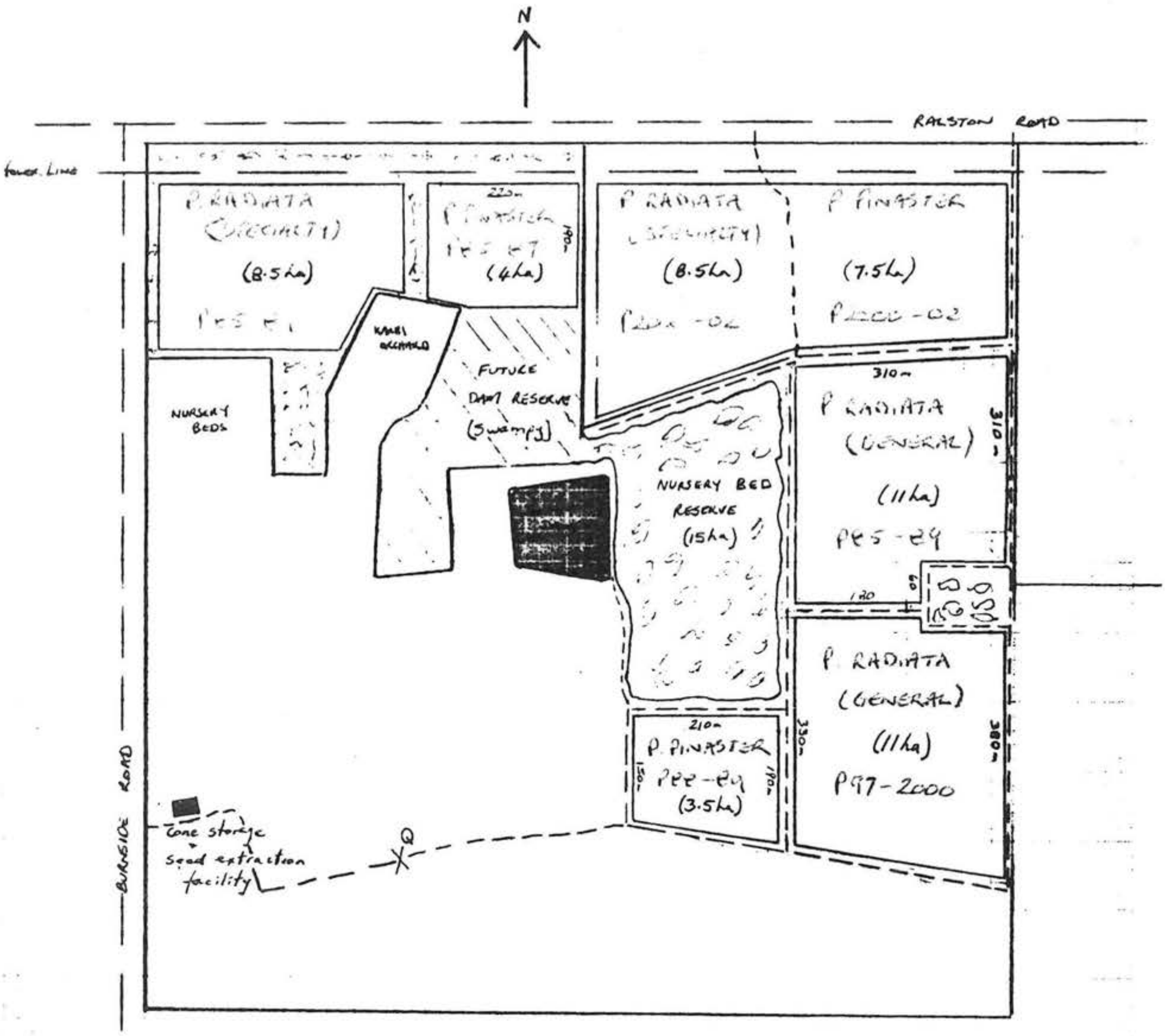
AUGUST PERCENTAGE FREQUENCY



WEST MANJIMUP FORESTRY CENTRE

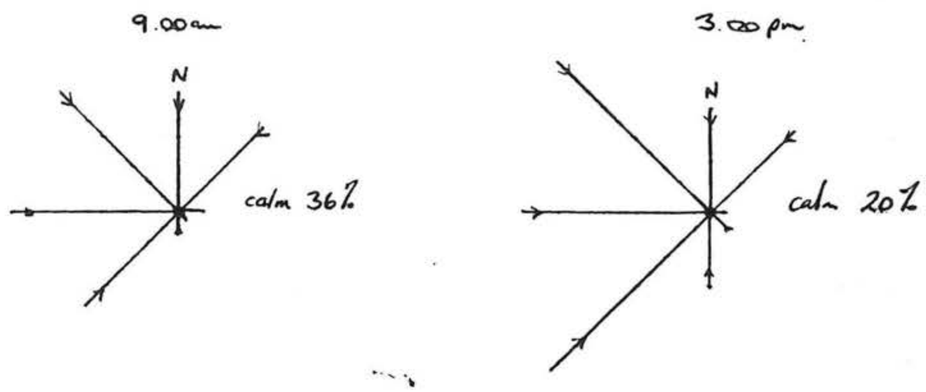
PINE SEED ORCHARDS

II – as at 1990



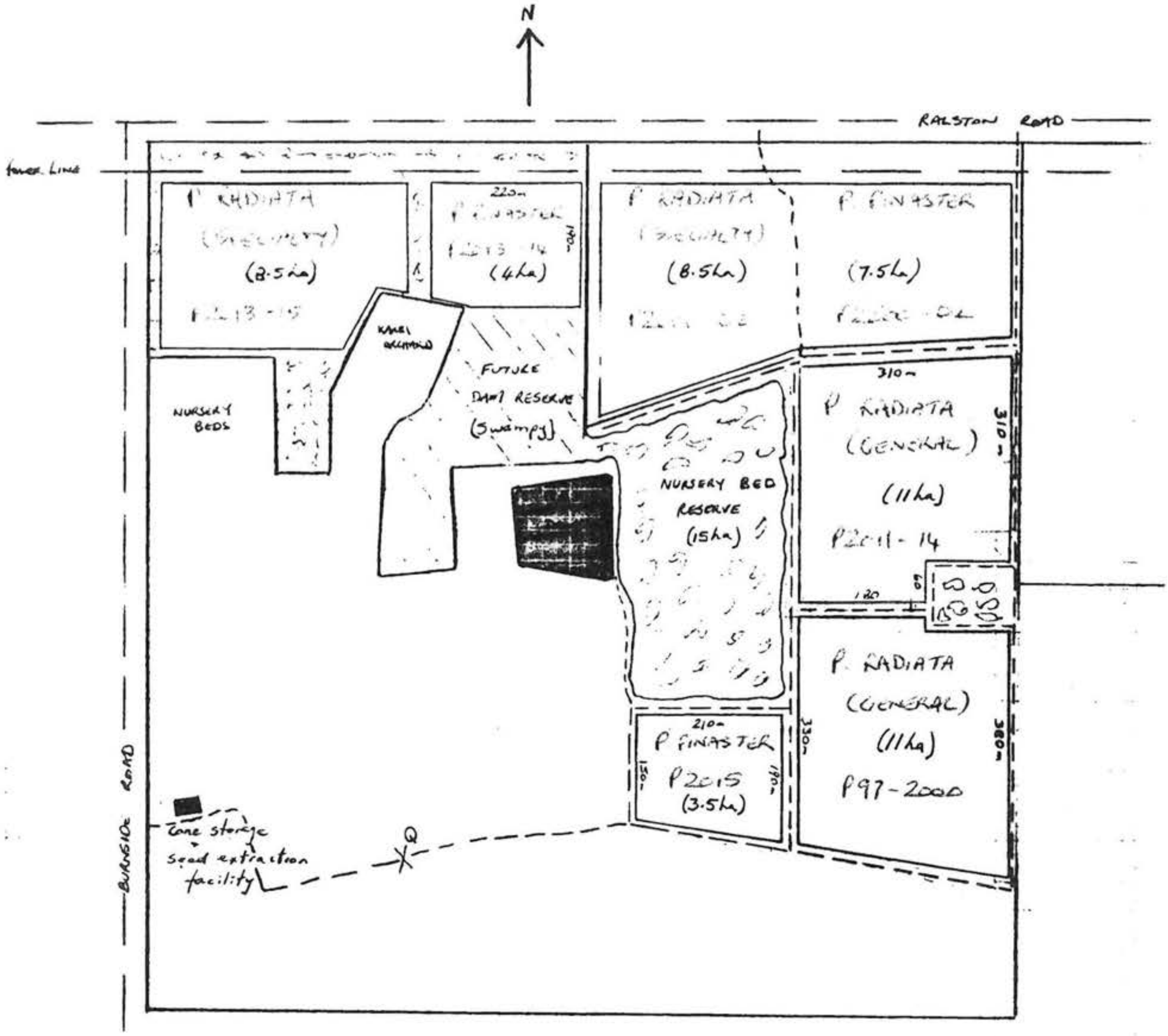
SCALE (APPROX) 1 cm = 84 m.

WIND DIRECTION AT MANJIMUP (1957–61)
AUGUST PERCENTAGE FREQUENCY



WEST MANJIMUP FORESTRY CENTRE
PINE SEED ORCHARDS

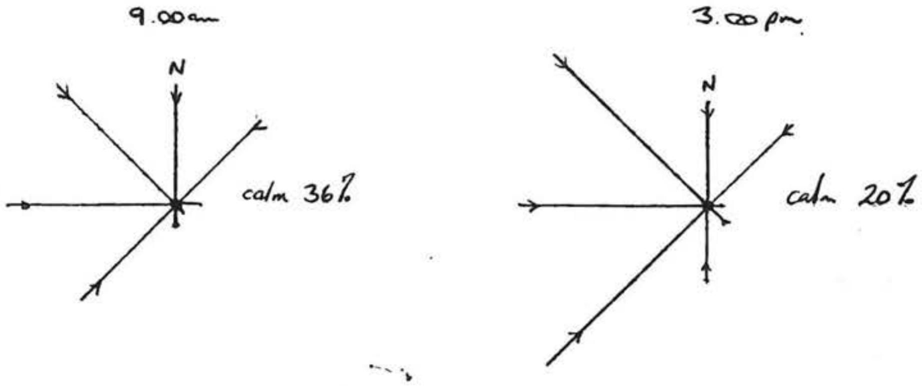
III – as at 2003



SCALE (APPROX) 1cm = 84m.

WIND DIRECTION AT MANJIMUP (1957–61)

AUGUST   PERCENTAGE FREQUENCY



WEST MANJIMUP FORESTRY CENTRE

PINE SEED ORCHARDS

IV – as at 2015

Area of orchards = 54ha

P. radiata (gen) – 22ha
P. radiata (spec) – 17ha
P. pinaster – 15ha