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GENETIC IMPROVEMENT OF EUCALYPTS IN NEW ZEALAND

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Tree breeding, integrated with an active programme of species and provenance testing, is being conducted in **Eucalyptus botryoides**, **E. saligna**, **E. regnans**, **E. delegatensis**, **E. fastigata**, **E. obliqua**, and **E. nitens**. The programmes involve provenance trials and family tests to give a broad base of genetic variability of the different species, and to form genetically improved local seed sources. Several other species are being tested on a small scale.

Selection criteria vary somewhat among the 7 main species, but fast growth, good stem form and branching characteristics, and useful wood are needed in all species. Genetic variation of practical significance has been found in the tolerance of **E. regnans** and **E. fastigata** to frost. Considerable emphasis is being placed on searching for strains of **E. nitens** which are less palatable to the Eucalyptus tortoise beetle, **Paropsis charybdis**.

The breeding method used entails selecting the best trees in the most promising provenances, followed by intermating among these to produce the improved seed via seed stands, seedling seed orchards, clonal seed orchards, and progeny-tested seed trees.

INTRODUCTION

At present, eucalypts are of only minor forestry importance in New Zealand, although they are common as farm trees in most districts. Planting on a commercial scale is confined to a few selected "working circles" where good sites are available and where prospects appear bright for developing and sustaining profitable markets for the wood. Elsewhere, small areas of eucalypts continue to be planted for shelter, for landscaping, and for farm timber and firewood.

A steady demand for seed of several species, an almost total lack of quality control in seed collection operations, and the recognition that certain weaknesses in otherwise excellent species might be eliminated by provenance selection or breeding, led to the initiation of genetic improvement programmes in 7 *Eucalyptus* species in New Zealand during the period 1973-79. The aim of these programmes initially is to identify and provide reliable seed sources of satisfactory provenance so that planting programmes can proceed with confidence. The programme in each species has a broad base of genetic variability and thus incorporates a sound basis for longer term breeding and for more refined species evaluation and comparisons.

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SPECIES SELECTION

Species currently planted and included in improvement programmes

Species selection in *Eucalyptus* can be difficult (Turnbull & Pryor 1978), and in New Zealand is proving to be much less straightforward than it was in *Pinus*. Compared with radiata pine, eucalypts are generally very specific in their site requirements and present more difficulties and uncertainties in their end uses.

From observation of old eucalypt stands on a number of sites, from limited utilisation experience (e.g., Barr 1971; Hannah *et al.* 1977), and from preliminary results in recent formal species tests, the 7 species deemed worthy of attention in genetic improvement programmes are *E. botryoides, E. saligna, E. regnans, E. delegatensis, E. fastigata, E. obliqua,* and *E. nitens*. The first 5 are currently the most popular for planting.

In all, about 100 species of *Eucalyptus* are found regularly on farms, in park collections, and in woodlots in New Zealand. Species abundance varies considerably by locality (e.g., *E. saligna* is the commonest in Northland, *E. gunnii* and *E. delegatensis* in Southland). Selection criteria underlying the choice of the 7 top species are growth potential, range of site tolerances, log quality (branching and stem form), utilisation potential, cold resistance, insect and disease resistance, and resistance to mammal browsing. Silvicultural factors such as seed availability and ease of establishment can also be important. The best species to plant may become more obvious once intended end uses are known, and more experience with a wide spectrum of provenances has been gained over a range of climates, soils, and silvicultural regimes.

Continued faith in the ash group of eucalypts (Wilcox 1979) in New Zealand is noteworthy, as the subgenus *Monocalyptus* Pryor and Johnson to which the ashes belong is reported to have been rarely successful on a plantation scale when planted outside Australia (Turnbull & Pryor 1978). One reason why representatives of *Monocalyptus* such as *E. muellerana, E. pilularis, E. fastigata, E. globoidea,* and *E. pulchella* have often grown satisfactorily here could be that New Zealand's temperate climates reasonably match those of south-east Australia where a major section of *Monocalyptus* has its stronghold. Furthermore, the debilitation wrought by just a few insect species to many species of the subgenus *Symphyomyrtus* Pryor and Johnson that have been tried in New Zealand, more especially those of Section *Maidenaria* Pryor and Johnson, e.g., southern blue gums, cancels out any general adaptive advantage that this subgenus may have over the usually more insect-resistant *Monocalyptus* eucalypts. Apart from *E. saligna* and *E. botryoides* of *Symphyomyrtus,* both proven dependable trees in warmer parts of the North Island and with outstanding resistance to attack by the Eucalyptus tortoise beetle *Paropsis charybdis* Stål (Coleoptera : Chrysomelidae), most emphasis is on the ash-type eucalypts in the belief that some of these can be grown well in New Zealand, and will produce wood of good quality suitable for many uses.

New species trials

As well as the 7 species to which varying intensities of tree breeding commitment have been made, numerous other eucalypts are under test in species trials. For wood production, the Forest Research Institute is testing (or re-testing) the following species:

andrewsii subsp. **andrewsii**
andrewsii subsp. **campanulata**
consideniana
cypellocarpa
dalrympleana subsp. **dalrympleana**
deanei
dendromorpha
diversicolor
dunnii
fraxinoides
globoidea
globulus subsp. **globulus**
grandis
gunnii
jacksonii
johnstonii
microcorys
muellerana
oreades
pilularis
pyrocarpa
sieberi
stenostoma
triflora
viminalis

To provide a sound basis for judging the potential of these species and for an early indication of preferred seed sources, several provenances of each species are being tested, where possible, on several sites. Noteworthy omissions from the list are *E. macarthurii* and *E. ovata,* two of the commonest and least desirable species in New Zealand. However, the widely planted and formerly popular *E. globulus* subsp. *globulus,* usually plagued by insects, has been given another chance.

Further eucalypt species trials are being conducted by N.Z. Forest Products Ltd near Tokoroa and in Northland. Species being tested in addition to those in the Forest Service tests are *E. globulus* subsp. *bicostata, E. glaucescens, E. kartzoffiana, E. smithii,* and *E. globulus* subsp. *maidenii* at Tokoroa, and *E. resinifera, E. robusta, E. maculata,* and *E. cloeziana* in Northland (B. R. Poole, pers. comm.). Also in Northland, the Auckland Conservancy of the N.Z. Forest Service has recently established a trial of 4 Western Australian timber species, *E. patens, E. brevistylis, E. wandoo,* and *E. calophylla.*

There is considerable interest in some regions in testing eucalypts for erosion control and shelter. The Ministry of Works and Development, in conjunction with the Wairarapa Catchment Board, has recently established a series of trials to find eucalypts suitable for arresting soil erosion on the eastern side of the North Island. The list of candidates is (R. L. Hathaway, pers. comm.):

agglomerata
aggregata
albens
amplifolia
amygdalina
badjensis
barberi
blakelyi
bosistoana
botryoides
brookerana
camaldulensis
camphora
cinerea
cladocalyx
coccifera
cordata
cypellocarpa
dalrympleana subsp. **dalrympleana**
deanei
delegatensis
dives
dunnii
elata
fastigata
fraxinoides
globoidea
gunnii
johnstonii
kartzoffiana
kitsoniana
kybeanensis
laevopinea
leucoxylon subsp. **megalocarpa**
leucoxylon subsp. **pruinosa**
macrorhyncha subsp. **macrorhyncha**

maculata	**regnans**
mannifera subsp. **mannifera**	**risdonii**
melliodora	**robusta**
muellerana	**rubida**
nitens	**saligna**
nitida	**sideroxylon** subsp. **sideroxylon**
obliqua	**sieberi**
odorata	**smithii**
oreades	**stellulata**
ovata	**tenuiramis**
pauciflora subsp. **pauciflora**	**tereticornis**
polyanthemos	**urnigera**
pulchella	**viminalis**
radiata subsp. **radiata**	

Trials of some hardy species have been established at an altitude of 1000 m in Canterbury by the Protection Forestry Division of the Forest Research Institute. The species being tested are (N. J. Ledgard, pers. comm.):

cypellocarpa	**parvifolia**
coccifera	**pauciflora** subsp. **pauciflora**
dalrympleana subsp. **dalrympleana**	**pauciflora** subsp. **niphophila**
delegatensis	**perriniana**
glaucescens	**rubida**
johnstonii	**stellulata**
nitens	**viminalis**

GENETIC BASE

It is widely thought that the genetic base in plantation tree species should not be allowed to become too narrow. This applies especially to the breeding population maintained as the immediate source of new selections for the next generation. It also applies to the commercial tree crop itself planted from genetically improved seed where a diversity of genotypes is considered good insurance against unforeseen events such as the arrival of new diseases.

Each of the 7 species chosen for breeding programmes has a suitably wide altitudinal and latitudinal range, or has a sufficiently disjunct distribution, to suggest that provenance variation could be important. Thus, a random sample of genes, such as may be obtained from seed collection in a single population is unlikely to be a sufficiently good base for breeding, no matter how carefully climates of the seed source and potential planting site were matched. This is not to say that certain provenances of superior general adaptability cannot be found and eventually used as the ultimate breeding population.

The entire natural occurrence of the species should initially be considered as the potential genetic base for introducing and undertaking genetic improvement in a eucalypt. Just how comprehensive the genetic sample needs to be to ensure all potentially valuable genes are available for future breeding depends on the natural distribution of the species, known or inferred ecological ranges, and probable genetic differentiation patterns. For example, prior knowledge of provenance variation in the widely-distributed *E. obliqua* (Brown *et al.* 1976) suggests that South Australian populations of this species are unlikely to be useful in New Zealand either as immediate seed sources for commercial planting or as components of a gene pool for breeding. On the other hand, there appears to be no sound basis for excluding any natural populations of *E. regnans* from representation in a breeding programme; consequently a rather wide collection of seedlots of this species has been introduced.

Eucalypt plantations in New Zealand

Most early eucalypt introductions to New Zealand were haphazard and the origins are unrecorded or lost. The eucalypt enthusiasts of the past have left a legacy of scattered small woodlots and shelterbelts that are of some help in species evaluation, but of questionable value as a gene resource for breeding.

The amount of seed available from a single eucalypt tree can be prodigious, and could be sufficient to establish many hectares of plantations. Thus, even in stands where the general seed origin has been recorded, the number of seed trees represented in the seedlot is nearly always unknown, but can usually be assumed to be very few (cf. Eldridge 1978).

Local stands of eucalypts, although mostly of unknown origin and narrow genetic base, can nevertheless make a valuable contribution to the gene pool for breeding. They have an immediate advantage over fresh importations of native provenances because they have been already tested in local environments, perhaps with some degree of natural selection and consequent adaptation. They also provide an opportunity for reasonably intensive and effective artificial selection to be exercised, which is not always possible in wild stands.

Since genetic sampling error (genetic drift) could have resulted in the chance loss or fixation of certain alleles in these narrowly based New Zealand stands, and individuals within stands are probably related (e.g., half sibs or even full sibs), the resultant progeny from such stands will be inbred. The selection strategy adopted in developing eucalypt breeding programmes from local stands of unknown origin has been to limit the number of trees selected per stand to just a few (e.g., 1–10), but to select from many different stands. This should have lessened the risk of burdening the breeding programme with an unreliable or sub-optimal provenance, have helped to broaden the genetic base, and should reduce inbreeding in seed orchards. Crossing among unrelated, but probably inbred, trees from different stands is expected to restore heterozygosity and boost tree vigour run down by accumulated inbreeding.

New provenance introductions

The best way of broadening the genetic base for breeding is to assemble seed and set up plantations from a comprehensive sample of trees from the species' natural range. This has recently been accomplished in New Zealand for several eucalypts by the establishment of provenance tests, and also by importation and planting of commercial seedlots from a limited number of native provenances. Both methods of introduction are useful, and complementary, in shaping the gene pool. The provenance tests tell which populations are best, as well as giving a diverse source of genotypes for selection; the commercial or "bulk" plantings, so long as the provenances turn out to be satisfactory, provide stands for future selection and seed collection.

In co-operation with seed suppliers in Australia, including private seed merchants and State and Commonwealth forestry departments, the New Zealand Forest Service through its Production Forest Management Division and Forest Research Institute has introduced and established a range of seedlots of the major eucalypt species. The various conservancies of the N.Z. Forest Service and the Forestry Department of N.Z. Forest Products Ltd have played a vital role in this programme of gene resource introduction by helping with the establishment of formal provenance tests, and by planting out pure blocks of specific, selected provenances for future reference.

The seed register and compartment records systems maintained diligently by the N.Z. Forest Service since the early planting years are proving to be indispensable in the management of the eucalypt gene resource now available for seed collection and breeding. Authentic records of where seedlots were collected and eventually planted are often very useful in tracing the origins and judging the genetic merit of various stands. Particularly with eucalypts, the seed register would be even more helpful in gene resource management if seed suppliers and collectors recorded the number of seed trees represented in a given seedlot.

SELECTION AND TESTING

Selection criteria

To justify a breeding programme the species should be potentially worth planting on a reasonable scale and likely to remain a permanent choice in planting programmes. The case for tree improvement can also rest on there being a realistic expectation that selection and breeding will generally upgrade the species or overcome certain deficiencies to a degree that will increase the species' economic value, and enhance its forestry status.

What should be selected for in eucalypts? In the New Zealand eucalypt improvement programmes, selection for better silvicultural characteristics has initially been emphasised because of the simplicity of visually screening candidate trees for diameter growth, stem straightness, and branching features, including natural pruning. More specific selection criteria may in some cases be of over-riding importance; examples include better resistance to insect pests such as the Eucalyptus tortoise beetle *Paropsis charybdis* (e.g., in *E. nitens*), better frost resistance (e.g., in *E. regnans* and *E. fastigata*), reduced end-splitting of logs (e.g., in *E. saligna*), and better apical dominance (e.g., in *E. fastigata*).

Little reliance can be placed on phenotypic selection of individual trees in the first generation to achieve important gains in these eucalypt programmes. This is because selection intensities for most traits are very restricted by the small areas of the individual stands available, and because stand-to-stand genetic variation will often be masked by differences among stands in age, site, and silviculture. It would be especially difficult to satisfactorily select for (or against) important commercial milling properties of the timber, including features such as severity of growth stresses (Barr 1980) and seasoning collapse, and incidence of kino veins (Bamber 1978). Such traits may well be strongly heritable, but superior individuals could be reliably detected only after comparison with several neighbours. Gains from selection would therefore be limited by the practical difficulties of achieving a significant selection intensity within stands, or by the lack of any valid genetical comparison of stands.

The most reliable way of identifying selection criteria which are heritable and of economic importance is to have family and provenance tests established on several sites, exposed to the selective pressures of weather, soil, diseases, and insects, and poised to reveal usable genetic variation. Selection for sawlog quality traits (freedom from knots and kino veins, reduced growth stresses, and minimal seasoning collapse) seems best left until progeny are old enough for the components of variation and heritabilities of these traits to be properly evaluated. To replace tedious selection procedures involving the milling and timber grading of individual plus-trees (e.g., Banks & Vuuren 1976), early, non-destructive tests that correlate well with product quality need to be developed.

Family testing

Most of the eucalypt breeding programmes in New Zealand are based on open-pollinated family tests. The mother trees of these families include plus-trees selected in New Zealand plantations or in native Australian stands, and some random (i.e., non-selected) trees from particular provenances.

A typical family test in the New Zealand programme comprises 100 families, drawn from several populations, planted on one or two sites. A single-tree plot layout has been employed in which the test site is divided into 36–48 blocks each containing one tree of each family. The objectives of these tests are:

(a) Progeny testing — testing the general combining ability of the mother trees and selecting the best for inclusion in clonal seed orchards or as seed trees for commercial seed collections.

(b) Family selection — identifying the best families for long term retention in the tests as parents of the next breeding generation, and for commercial seed production.

(c) Individual selection — identifying the best trees in the tests as parents in future clonal seed orchards.

(d) Estimating genetic parameters — giving information essential to conducting efficient and effective breeding programmes, e.g., heritability of traits, genetic correlations, relative amounts of genetic variation among and within provenances, juvenile-adult correlations, genotype × environment interactions, and gain from selection.

The single-tree plot design fulfils two purposes. One is to provide precise estimates of family means and genetic parameters, using quite small family sizes (e.g., 36–48 trees per family). The other is to minimise inbreeding (or maximise outcrossing) in the test once the best individuals in it have been identified, and retained *in situ* as the parents of the next generation.

Open-pollinated families of eucalypts provide a simple and rapid method of initiating an improvement programme. However, their validity for testing, selection, and estimation is uncertain since, for a given set of families, the mean co-ancestry among individuals within a family probably varies widely from family to family. For example, some families could consist mainly of selfs, others mainly of full sibs. The interpretation of differences among open-pollinated families of eucalypts thus requires considerable caution, though selection of only the best families (or their mother trees) should still be effective and robust over a range of departures from the strictly half-sib relationship usually assumed within families. Controlled-pollination mating designs have initially been ruled out of the New Zealand eucalypt programmes because of practical difficulties.

SEED PRODUCTION SYSTEMS

There are numerous breeding options available for producing improved seed of eucalypts. Flexibility in approach is advisable to allow for changes in species "fashion", unforeseen problems in seed harvesting, graft incompatability problems, and the likelihood of changes in selection criteria. The breeding methods adopted in New Zealand are firmly based on selection of the best provenances, together with selection for general combining ability and maintenance of maximum heterozygosity. This entails selecting the best trees from the best provenances, and inter-mating these to produce the improved seed.

A certain amount of inter-provenance hybridisation among the best provenances will be inevitable in several of the breeding methods proposed which entail direct conversion of tests into seed sources. This could vary from little more than crossing between parents derived from different seedlots of the same general provenance, to rather wide crossing between selected parents from separate native populations. The early and deliberate incorporation of inter-provenance hybridisation into the breeding programmes is founded on the belief that the resultant genetically mixed seedlots should be better adapted to a range of planting sites and they should generally grow faster than narrowly based, comparatively inbred lots collected from native or exotic stands. The growth superiority of heterogeneous, well-mixed seedlots from exotic stands over native seedlots has been repeatedly demonstrated in conifers and should apply also to eucalypts. Caution is needed lest the concept of wide crossing is taken too far or applied indiscriminately to all species. Extremely wide crossing, such as could be conceived, for example, between provenances of *E. delegatensis* from low elevations in southern Tasmania and from high elevations in the Snowy Mountains of New South Wales, would have no predictable outcome and offer no certainty of genetic improvement.

Provenance seed stands

This is a simple breeding method, yet it should be very effective where there is prior knowledge that the chosen provenance is a good one. The steps to be taken are procurement of seed from numerous trees (the more the better) from a specified locality in Australia, establishment of plantations, and selective heavy thinning of stands to remove the poorest trees and encourage seed production on the best. Before planting, culling of obvious weaklings from the nursery beds would be worthwhile. Where there are doubts about the suitability of the provenance or about there being enough mother trees represented, seed from several seedlots could be mixed to provide a measure of safety, and perhaps even some heterosis from inter-provenance hybridisation.

Some existing eucalypt plantations in New Zealand have proved suitable for immediate use as provenance seed stands because their seed origin was known or because seedlots collected there have performed well. There are examples, however, of good-looking local stands turning out to be unsatisfactory seed sources (Wilcox *et al.* 1980).

Seed collection in provenance seed stands is by climbing or felling. Species that produce heavy seed crops at an early age (e.g., *E. fraxinoides, E. delegatensis, E. sieberi*) are particularly suited to the seed stand approach.

Seedling seed orchards

This is the general term denoting seed sources developed directly from plantations of selected families. Both *extensive* seedling seed orchards, in which family identity is lost (i.e., seed from individual selected trees is bulked), and *family* seedling seed orchards, in which family identity is retained, are planned. These orchards may be of restricted provenance base as in *E. delegatensis* where all the parents were selected from New Zealand stands of probably common origin; or they may have a broader genetic base, with the individual families drawn initially from several provenances. Wide-base family seedling orchards are being employed for *E. saligna, E. nitens, E. fastigata,* and *E. regnans,* but it will be some years before thinnings are made and seed can be collected. Also in hand for *E. nitens* are separate extensive seedling seed orchards of three broad provenances from central Victoria.

In the proposed seedling seed orchards, to be formed from family tests, the original parents were phenotypically selected and additional improvement will be obtained by culling among the progeny. Seed collection will be by climbing or felling.

The main difficulty in converting family tests into seedling seed orchards is in the conflicts which may arise in managing the trees for the dual purposes of seed production and selection. The trees need to be spaced widely for early, heavy seed production, and kept more or less open-grown to maintain seed production at a workable height in the crowns. Yet early thinning could necessitate premature selection of the trees to be retained as seed parents.

Individual tested seed trees (= certified seed trees)

After the initial results from the family tests are known, it can be feasible to return to the original mother trees and collect seed in commercial quantities from those shown to produce the best progeny. This method is possible where seed requirements are small. It has been used in collecting a seedlot of *E. regnans* at Tokoroa where early test results on frost resistance were available (Wilcox *et al.* 1980), and superior mother trees had enough seed to make up a commercial seedlot.

In addition, some small seedlots of certified superior value have been concocted and distributed using remnant seed of the best families held over in storage from the original collections.

Clonal seed orchards

Clonal seed orchards from grafts of local plus-trees have so far been developed only for *E. botryoides, E. saligna,* and *E. regnans.* The first commercial harvests of seed were made in January 1980, when a total of 1.5 kg of seed of *E. botryoides* was collected from 15 grafts, 6 years after the grafts were planted.

The grafting technique developed at the Forest Research Institute (Thulin & Faulds 1962) is as follows: All eucalypts are cleft grafted and best results have been from grafting done from December to March. The key to success is the condition of the scion material which must be free of damage, lack flower primordia and developed buds, and have at least 3 leaf axils from which new growth can quickly spring after grafting. The most suitable scions are obtained from short lengths of slender shoots collected (usually by rifle) from the extremities of the crown. Before the scion is grafted, leaf laminae are cut off but short petiole stubs are retained. Root stocks must be young, vigorous, and healthy. Three-month-old potted seedlings grown specifically for root stock are most suitable, and these must be ready at the same time as scions are collected. Woody, spindly, open-rooted seedlings are unsatisfactory as root stocks.

The clonal orchard is a convenient seed production method for eucalypt species which do not produce much seed until they are too tall to be economically or safely climbed. The grafts can be established at wide spacings and tended for maximum seed production. Grafting offers a flexible method of using new selections in the future, and incorporating them into improved strains. *Eucalyptus regnans, E. saligna, E. botryoides,* and *E. fastigata* are the species to which clonal orchards are well suited and most needed. Only local plus-trees have been used, and no importation of scion material from Australian programmes has been attempted.

Species hybrids

The possibility of producing F1 hybrids between pairs of related eucalypt species is already apparent in the present programme, with spontaneous hybrids appearing regularly in locally collected seedlots from mixed stands or old species collections. Hybrids within the ash group of the subgenus *Monocalyptus* (Wilcox 1979) have been noticed (e.g., *E. regnans* × *E. delegatensis*), and there are numerous stands containing what appear to be *E. saligna* × *E. botryoides* hybrids.

No systematic, controlled hybridisation work has been done, but there is obvious scope for experimentation, particularly in the ash group where there are intriguing prospects for developing a "super ash" hybrid combining the best features of the major species. Work along these lines is not planned for the near future, and must wait until the potentials of the pure species have been more fully explored. At least among species of the ash group, no obvious heterosis has been observed in F1 species hybrids. Current policy is to treat hybrids as undesirable contaminants, and care is being taken to avoid hybridisation in seed stands and orchards.

INDIVIDUAL BREEDING PROGRAMMES

Eucalyptus botryoides

The best of the numerous stands of this species in the North Island are very good. Seed origins are mostly unrecorded, though a few young stands are from seed importations from the Orbost district in eastern Victoria where the species is near its southern natural limit.

Two strains can commonly be recognised in New Zealand:

(1) Barr/Woodhill strain: a good type with straight stem, moderately thick bark, and excellent resistance to insect pests. In appearance, the trees closely resemble those in a stand at Woodhill Forest derived from a seedlot collected in Bodalla State Forest on the south coast of New South Wales. The Barr/Woodhill strain itself originated from seedlings (of unknown origin) supplied by a nursery to Mr Neil Barr of Kaukapakapa, Northland, who planted woodlots and shelterbelts on his farm. These plantings were very successful, yielding useful farm timber and shelter, and duly became the seed source of many further farm plantations in Northland and of numerous, small, excellent stands on moist sand-dune sites in Woodhill Forest west of Auckland. The Woodhill stands in turn have been used frequently in recent years as a source of seed.

(2) Thick-barked strain: this has a distinctive bark that is deeply furrowed, thick, and spongy, and can be readily torn off in chunks. The stem is usually crooked or leaning, and the crown heavy and untidy. It is suspected that this coarse type of *E. botryoides* originated from seashore populations in New South Wales. Wherever it came from, it is a poor strain for forestry.

The specific role of *E. botryoides* in New Zealand forestry is uncertain. At its best, it can be bracketed with *E. saligna* in terms of siting, yields, and timber properties.

Clonal seed orchards of grafts of 17 plus-trees selected for diameter growth, crown form, and stem straightness from a stand in Woodhill Forest derived from a Barr seedlot were established at Woodhill and Rotorua in 1974–75. The first commercial seed harvest, totalling 1.5 kg, was made in January 1980, although ripe fruits occurred sporadically as early as 1978. The grafts have been kept short by annual topping, with some sacrifice in seed yields. A problem in the orchards has been wind breakage, to which the species seems very susceptible but, in general, the clonal orchard concept has worked well as a method of seed production in this species.

No provenance or family testing has been carried out in *E. botryoides,* and the breeding programme is essentially a means of producing easily collected seed of an apparently good local strain. Some good-looking young stands of Orbost provenance have been noted as additional seed sources.

Eucalyptus saligna

This is currently the main eucalypt planted north of Rotorua, and its popularity is supported so far by early results from species tests. Provenance tests of several native and exotic provenances, and family tests of 43 native, 55 New Zealand, and 2 American (Hawaii and Brazil) mother trees were established in 1976 (Wilcox *et al.* 1980). Grafted clonal seed orchards of 40 New Zealand plus-trees were also planted out in 1976, and there is an earlier (dating back to 1965) clonal orchard from grafts of 9 outstanding plus-trees in Northland.

Objectives of the programme are to find provenances or breed varieties with superior growth rate, good form, and, eventually, better wood properties. Susceptibility to animal browsing (especially by possums and rabbits) and to wind breakage are specific problems of *E. saligna* that are unlikely to be solved by breeding.

The so-called "Bartlett's" strain from Silverdale has the reputation of producing a good quality, often highly-figured wood (wavy grain) with excellent sawing and seasoning properties. Second-generation trees at Kaukapakapa have also consistently milled well (Barr 1980). However, early results from progeny tests show that trees from the Bartlett property produce comparatively slow-growing progeny. There is thus a suggestion that selection for timber quality could be at the expense of growth rate, and vice versa.

A seedlot from Kangaroo Valley, located inland and up the steep scarp above Nowra, New South Wales, has produced the fastest growing progeny in all New Zealand tests, and is the currently recommended native provenance should further seed importations be needed (Wilcox *et al.* 1980). The stands in Kangaroo Valley and on the nearby Barrengarry and Cambewarra Mountains are near the southern end of the species' range. Another particularly vigorous seedlot was from Batemans Bay on the coast, close to the northern limit. Nothing is known about the timber properties of these fast-growing strains.

Clonal seed orchards are very promising in this species and it should be only 2–3 years before most seed requirements can be met from orchards. The orchard planted at Rotorua in 1976 with 40 clones is already producing a little seed, and was thinned in 1979 to remove 12 clones with incompatible grafts and/or that performed poorly in progeny tests. In progeny tests, the best of the New Zealand clones in the orchard (mainly from Athenree, Kerikeri, and Rotoehu) are so far (results at age 3 years) performing as well as, or better than, the Kangaroo Valley and Batemans Bay provenances; thus, for first-generation orchards, at least, the breeding programme appears to be soundly based.

Based on the evident vigour and consistent compatibility of their mother clones as grafts, several families have been provisionally selected for use as root stocks in the hope of reducing graft incompatibility. If this is successful, it will enable orchards to be upgraded or renewed without troublesome grafting losses.

Half-barked trees suggestive of *E. saligna* × *E. botryoides* are common in New Zealand woodlots and are often among the best trees in the stand. A hybrid breeding programme is thus a possibility for the future. The reasonably dense wood and good coppicing ability of these two closely related species, together with their obvious adaptation to northern New Zealand sites, make them attractive prospects for short-rotation fibre cropping. The breeding programmes will thus be maintained at a reasonable pace to meet any future demands for large quantities of seed.

Eucalyptus regnans

This species looks to have great potential in the central North Island, and in milder localities of the South Island. A comprehensive breeding and seed supply programme is under development. Major provenance and family tests were established in 1977.

The main breeding population comprises 144 open-pollinated families (41 from Tasmania, 43 from Victoria, and 60 from New Zealand) of diverse provenance. Most of the mother trees of these families were phenotypically selected at low intensity for superior growth and stem form. The experimental design of the family tests (Wilcox *et al.* 1980) permits development of separate seedling seed orchards from Tasmanian and Victorian families, should this seem desirable. A much wider coverage of native provenances, each broadly represented by 15 or so random mother trees, was planted out in trials as bulked seedlots on several sites in 1977 and 1978.

The family and provenance tests have already yielded valuable information on genetic variation in frost resistance (Rook *et al.* 1980; Wilcox *et al.* 1980). The hardiest seedlots were from interior upland sites in south-central Tasmania (e.g., Moogara and Styx River), and from high elevations (900–1100 m) in Victoria. Luckily, some seed sources already available in New Zealand have proved to be of near-maximum frost hardiness. Rapid attainment of genetic improvement in hardiness is therefore possible, with immediate benefits to the success of planting programmes.

There was severe infection of leaves and stem tips of 1- to 2-year-old trees by the fungus *Mycosphaerella nubilosa* (Cke.) Hansf. (Ascomycetes : Dothideaceae) in the central North Island in the wet summer of 1979–80. Preliminary examination of family and provenance tests indicates genetic variation in susceptibility.

A clonal seed orchard of grafts of 18 New Zealand plus-trees has been established at Rotorua. Although the initial success of grafting scions from the plus-trees on to seedling root stock was erratic, subsequent survival, stock–scion compatibility, and flowering of grafts have been most satisfactory. It is planned to periodically add further clones to the orchard (and to eliminate others), capitalising on the latest progeny test information to select the genetically superior plus-trees.

Better definition of breeding objectives should be possible once family tests are old enough to reveal information on variation and inheritance of economically important traits, including wood properties.

Eucalyptus delegatensis

This has been the most commonly-planted eucalypt in State forests, although interest has recently dwindled through doubts about the timber's propensity for internal and surface checking during seasoning, and the susceptibility to *Mycosphaerella* leaf blotch disease. Major sources of seed have been West Tapanui Forest ("Crookston" strain) and subsequent generations of trees in Southland, and in Golden Downs Forest; Te Awa (Kaingaroa Forest); and Karioi–Rangataua. The original Crookston, the Karioi Headquarters, and the Te Awa sources still exist, and are shelterbelts each of probably very restricted genetic base. They are of mainland (New South Wales or Victoria) origin, judging from seedling morphology and from bark characteristics.

A comprehensive set of provenance trials was established in 1977–78, based on range-wide seed collections organised by CSIRO, Canberra. In addition, 52 open-pollinated families from plus-trees selected in New Zealand plantations (Kaingaroa, Karioi, Rangataua, Whirinaki, Longwood, Rowallan, Golden Downs) are being tested. These family tests could ultimately be developed into seedling seed orchards, as well as serving as progeny tests of local plus-trees.

Commercial seed has recently been imported from a range of localities to diversify the genetic base of this species in New Zealand. Plantations from these seedlots can be treated as provenance seed stands should the seedlots perform well in provenance trials. Early observations show that southern Tasmanian seedlots are the least frost hardy, and high elevation New South Wales seedlots (e.g., Snowy Mountains) are the most frost hardy provenances in the species. Firmer choices of provenance for New Zealand sites must await more comprehensive results from the trials.

The only "improved" strain of *E. delegatensis* presently available is a thinned provenance seed stand at Kaingaroa Forest, derived from seed from Bago State Forest, New South Wales. This 5 ha stand, planted in 1972, has so far yielded 70 kg of seed.

Present selection objectives in this species include better frost hardiness, improved growth rate and stem form, and resistance to *Mycosphaerella nubilosa.*

As for *E. regnans* and *E. obliqua,* Bass Strait provides a natural barrier between Victorian and Tasmanian populations of *E. delegatensis.* In the former two species, the apparent barrier to gene flow by the present 300-km-wide strait appears to be of quite recent origin. This is evidenced by the absence of obvious morphological differences in these species in progenies from populations bordering either side of the strait. In *E. delegatensis,* however, there are such consistent and well-marked genetic differences between mainland and Tasmanian provenances in certain seedling characteristics (e.g., leaf shape and presence or absence of raised oil glands on the twigs) that long-standing genetic isolation must be inferred. No taxonomic recognition has ever been afforded these two unmistakable subdivisions of the species. Regardless of whether or not the genetic differentiation is really strong enough to require formal erection of subspecies, the present evidence suggests that Tasmanian and mainland populations are sufficiently different to warrant their separation in a tree improvement programme.

Eucalyptus fastigata

The programme in this species is based on 48 families from local plus-trees (Kaingaroa, Rotorua, Oakura, Hunterville, Cambridge), 6 families from South Africa, and 73 families from various native Australian populations.

The species has been grown successfully throughout New Zealand, and is one of the healthiest and most adaptable of the eucalypts tried here. Its worst feature is the tendency of the crown to break up early into heavy branches, but it is hoped that this defect can be reduced by selection and better silviculture. Other breeding objectives are better frost resistance and faster growth.

Artificial frost screening of several native and exotic seedlots has shown clearly that high elevation provenances in the northern part of the species range in New South Wales (e.g., Barrington Tops, 1400 m) are the hardiest (Wilcox *et al.* 1980). The southernmost provenances (e.g., East Gippsland, Victoria) and lower elevation provenances (e.g., Robertson (730 m) in New South Wales) are the most frost tender. Seedlots collected from the extensive plantations at Oakura, Taranaki, appear to be of average hardiness for the species, with good early vigour. Oakura is the currently favoured local commercial seed source of this species.

As progeny test results become available from trials planted in 1979, it is intended to establish a clonal seed orchard of grafts from the best local mother trees.

Eucalyptus obliqua

Of the commercial eucalypts of the ash group, *E. obliqua* has the widest natural occurrence. Provenance variation in growth rate and other features is very pronounced in Australian tests and could explain the variable, often disappointing performance of this species in New Zealand. The natural ecology of *E. obliqua* in Australia suggests it ought to be better suited than either *E. regnans* or *E. delegatensis* to mild sites in low rainfall areas (e.g., 600–900 mm/year). Its present reputation in New Zealand is not high, though this is probably not well founded. There are a few excellent stands, and some good reports on timber quality from farm trees.

The first positive step in the genetic improvement of *E. obliqua* in New Zealand has been to import seed from 62 individual trees sampled randomly from populations at Strathblane (Tas.), Mawbanna (Tas.), Nietta (Tas.), Powelltown (Vic.), and Lavers Hill in the Otway Ranges (Vic.). These provenances were the best in Australian tests (Brown *et al.* 1976) and have now been included in species and provenance tests in New Zealand. They should provide an optimal genetic base from which a more elaborate tree improvement programme could eventually be developed, if desired.

By maintaining some sort of breeding effort in this species, it should be possible to select superior material suitable for use in an *E. obliqua* × *E. regnans* hybridisation programme. Promising results have been obtained in Australia with intermediate forms (natural hybrids?) from the Otway Ranges, Victoria, and thus systematic crossing between the best provenances of each species could produce hybrid strains of outstanding merit for certain sites.

Eucalyptus nitens

"Shining gum" has had a rather brief history as a forestry tree in New Zealand. Its impressive early vigour over a wide range of sites, ease of establishment, and good frost hardiness are its main silvicultural virtues. Problems include persistence of branches and susceptibility to *Paropsis charybdis* and possibly other insect pests. Wood properties are little known from plantations. Admiration for the extreme vigour of this species in the first 3 years should be tempered by the dismal history in New Zealand of the related *E. globulus* subsp. *globulus.* Unless susceptibility to *P. charybdis* can be substantially reduced by breeding, or effective biological or chemical control measures can be found, it is doubtful whether *E. nitens* will ever fulfil its potential in New Zealand.

Several provenance tests of *E. nitens* have been established, covering all the main natural populations. In addition, family tests of 80 mother trees from the promising Rubicon, Toorongo, and Macalister populations from central Victoria (Pederick 1979) have been widely established as a basis for a thorough evaluation of the species and for assessing the genetic variation in important traits. After thinning, the tests should eventually become valuable family seedling seed orchards, although there could be a long wait for seed.

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APPENDIX Botanical names, authorities, and standard common Australian names of eucalypts mentioned in the text

Eucalyptus agglomerata Maid.	blue-leaved stringybark
Eucalyptus aggregata Deane & Maid.	black gum
Eucalyptus albens Benth.	white box
Eucalyptus amplifolia Naudin	cabbage gum
Eucalyptus amygdalina Labill.	black peppermint
Eucalyptus andrewsii Maid. subsp. **andrewsii**	New England blackbutt
Eucalyptus andrewsii Maid. subsp. **campanulata** (R.T.Bak. & H.G.Sm.) L. Johnson & D. Blaxell	New England ash
Eucalyptus badjensis de Beuzev. & Welch	Big Badja gum
Eucalyptus barberi L. Johnson & D. Blaxell	Barber's gum
Eucalyptus blakelyi Maid.	Blakely's red gum
Eucalyptus bosistoana F. Muell.	coast grey box
Eucalyptus botryoides Sm.	southern mahogany
Eucalyptus brevistylis Brooker	Rate's tingle
Eucalyptus brookerana A. M. Gray	Brooker's gum
Eucalyptus calophylla R. Br.	marri
Eucalyptus camaldulensis Dehnh.	river red gum
Eucalyptus camphora R. T. Bak.	mountain swamp gum
Eucalyptus cinerea F. Muell. ex Benth.	Argyle apple (silver dollar in N.Z.)
Eucalyptus cladocalyx F. Muell.	sugar gum
Eucalyptus cloeziana F. Muell.	Gympie messmate
Eucalyptus coccifera Hook. f.	Tasmanian snow gum
Eucalyptus consideniana Maid.	yertchuk
Eucalyptus cordata Labill.	heart-leaved silver gum
Eucalyptus cypellocarpa L. Johnson	mountain grey gum
Eucalyptus dalrympleana Maid. subsp. **dalrympleana**	mountain gum
Eucalyptus deanei Maid.	round-leaved gum
Eucalyptus delegatensis R. T. Bak.	alpine ash
Eucalyptus dendromorpha (Blakely) L. Johnson & D. Blaxell	Budawang ash
Eucalyptus dives Schau.	broad-leaved peppermint
Eucalyptus diversicolor F. Muell.	karri
Eucalyptus dunnii Maid.	Dunn's white gum
Eucalyptus elata Dehnh.	river peppermint
Eucalyptus fastigata Deane & Maid.	brown barrel
Eucalyptus fraxinoides Deane & Maid.	white ash
Eucalyptus glaucescens Maid. & Blakely	Tingiringi gum
Eucalyptus globoidea Blakely	white stringybark
Eucalyptus globulus Labill. subsp. **bicostata** (Maid. **et al.**) Kirkp.	southern blue gum
Eucalyptus globulus Labill. subsp. **globulus**	Tasmanian blue gum
Eucalyptus globulus Labill. subsp. **maidenii** (F. Muell.) Kirkp.	Maiden's gum
Eucalyptus grandis Hill ex Maid.	flooded gum
Eucalyptus gunnii Hook. f.	cider gum
Eucalyptus jacksonii Maid.	red tingle
Eucalyptus johnstonii Maid.	Tasmanian yellow gum
Eucalyptus kartzoffiana L. Johnson & D. Blaxell	Araluen gum
Eucalyptus kitsoniana Maid.	Gippsland mallee
Eucalyptus kybeanensis Maid. & Camb.	Kybean mallee ash
Eucalyptus laevopinea R. T. Bak.	silvertop stringybark
Eucalyptus leucoxylon F. Muell. subsp. **megalocarpa** Boland	yellow gum
Eucalyptus leucoxylon F. Muell. subsp. **pruinosa** (F. Muell. ex Miq.) Boland	yellow gum
Eucalyptus macarthurii Deane & Maid.	Camden woollybutt
Eucalyptus macrorhyncha F. Muell. ex Benth. subsp. **macrorhyncha**	red stringybark
Eucalyptus maculata Hook.	spotted gum
Eucalyptus mannifera Mudie subsp. **mannifera**	brittle gum
Eucalyptus melliodora A. Cunn. ex Schau.	yellow box
Eucalyptus microcorys F. Muell.	tallow wood
Eucalyptus muellerana Howitt	yellow stringybark
Eucalyptus nitens (Deane & Maid.) Maid.	shining gum
Eucalyptus nitida Hook. f.	shining peppermint
Eucalyptus obliqua L'Herit.	messmate
Eucalyptus odorata Behr ex Schlecht.	peppermint box
Eucalyptus oreades R. T. Bak.	Blue Mountain ash
Eucalyptus ovata Labill.	swamp gum
Eucalyptus parvifolia Camb.	small-leaved gum
Eucalyptus patens Benth.	Western Australian blackbutt
Eucalyptus pauciflora Sieb. ex Spreng. subsp. **pauciflora**	snow gum
Eucalyptus pauciflora Sieb. ex Spreng. subsp. **niphophila** (Maid. & Blakely) L. Johnson & D. Blaxell	alpine snow gum
Eucalyptus perriniana F. Muell. ex Rodway	spinning gum
Eucalyptus pilularis Sm.	blackbutt
Eucalyptus polyanthemos Schau.	red box
Eucalyptus pulchella Desf.	white peppermint
Eucalyptus pyrocarpa L. Johnson & D. Blaxell	large-fruited blackbutt
Eucalyptus radiata Sieb. ex DC. subsp. **radiata**	narrow-leaved peppermint
Eucalyptus regnans F. Muell.	mountain ash
Eucalyptus resinifera Sm.	red mahogany
Eucalyptus risdonii Hook. f.	Risdon peppermint
Eucalyptus robusta Sm.	swamp mahogany
Eucalyptus rubida Deane & Maid.	candlebark
Eucalyptus saligna Sm.	Sydney blue gum
Eucalyptus sideroxylon A. Cunn. ex Woolls subsp. **sideroxylon**	red ironbark
Eucalyptus sieberi L. Johnson	silvertop ash
Eucalyptus smithii R. T. Bak.	gully gum
Eucalyptus stellulata Sieb. ex DC.	black sally
Eucalyptus stenostoma L. Johnson & D. Blaxell	Jillaga ash
Eucalyptus tenuiramis Miq.	silver peppermint
Eucalyptus tereticornis Sm.	forest red gum
Eucalyptus triflora (Maid.) Blakely	Pigeon House ash
Eucalyptus urnigera Hook. f.	urn gum
Eucalyptus viminalis Labill.	manna gum
Eucalyptus wandoo Blakely	wandoo