Part 7. Breeding Programs

Eucalypt Improvement for California: Progress and Plans[1]

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Abstract: Six promising eucalypt species, suitable for fiber or biomass production, have been identified with some confidence: Eucalyptus camaldulensis, E. dalrympleana, E. viminalis, E. nitens, E. globulus, and E. grandis. The Forest Service's Institute of Forest Genetics has established provenance or seed source tests of E. camaldulensis, E. grandis, E. nitens, and the E. dalrympleana-E. viminalis complex. In E. camaldulensis, the Lake Albacutya source is outstandingly superior to any other, and can probably double yields previously achieved with this species in California. Growth among E. grandis provenances is more uniform, but gains of 32 percent may be made by seed source selection. Tests of other species are too young for firm conclusions. Once superior seed sources are identified, they should be used to fill planting demands in California. The next step is to begin selection and breeding within the most productive species.

California has a long history of flirtation with eucalypts, but little in the way of systematic programs to identify superior planting stock. Eucalypts (genus Eucalyptus) were introduced in California over 125 years ago and some have since become naturalized (Kirkpatrick 1977). Eucalypt windbreaks, road screens, and woodlots are so common that many laypeople believe eucalypts are native trees. But despite their familiarity, there have been few trials of eucalypts as timber trees. Most of our knowledge on their growth and adaptability is anecdotal, deriving from observations on scattered specimens (Metcalf 1924). Until recently there was little need of more intensive investigation because California has many fine conifers that are easily seasoned for construction lumber, while eucalypt timber is difficult to season. However, interest in eucalypts has increased because of their suitability for short-rotation fuel biomass plantations. Growers need a reliable source of rapidly growing planting stock, but development of eucalypt seed sources is not a small chore.

There are several stages in the development of any new crop. In the first stage, species trials are used to eliminate non-productive candidates and identify those with enough promise to justify further testing. However, even within a single species, the growth of one provenance (provenance = a population originating in a particular location, climate, and soil) may not be representative of the species. Therefore, species trials should include some minimum number of seed sources. Ideally, trials should be conducted on a number of sites to assure that results are not narrowly limited in application. Provenance testing is the primary objective in the second stage of introduction, to locate the best seed sources within the species. When yields are established for a range of provenances, the third stage can begin: intensive breeding methods are applied. within the best adapted provenances to improve growth and economic value.

SPECIES TRIALS

Choice of species is the first consideration in growing eucalypts, but a complete survey of the genus would be a monumental undertaking. A recent compilation recognizes 550 eucalypt species (Chippendale and Wolf 1981). Of these, at least 70 are grown in California (McMinn and Shepherd 1973). Many are in arboreta and parks, and their range of adaptability or their potential as forest trees is unknown.

One of the most extensive trials of eucalypt species was undertaken by the University of California Cooperative Extension. The University tested 43 species and 18 sites, although not every species was represented at each site (Davis [1980?]). Plantings spanned a latitudinal range from Yuba County to San Diego. After 7 years, the species were given a subjective rating based on their value as landscape trees. Appearance was heavily weighted in the rating. The highest score was

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Table 1--Survival and volume of eucalypt species from two plantings at Concord, California, 1977.

Species	1964 planting		1965 planting	
	Survival (pct)	Vol/tree (cu m)	Survival (pct)	Vol/tree (cu m)
E. camaldulensis	--[1]	--[1]	65	0.06
E. dalrympleana	65	0.29	60	0.02
E. ovata	29	0.28	24	0.10
E. grandis	13	0.20	91	0.07
E. nitens	54	0.19	94	0.13
E. viminalis	83	0.14	75	0.02
E. glaucescens	35	0.15	72	0.03

[1]Not planted in 1964

received by southern mahogany (E. botryoides Sm.), and it was followed by river red gum (E. camaldulensis Dehnh.). Actually, growth of river red gum was better than that of southern mahogany wherever they were planted together, but river red gum was not considered as suitable a landscape tree as southern mahogany. Because of the concentration on ornamental trees, many common timber trees were not included in the trials.

Species trials that focused primarily on timber trees were established at Concord, California, in 1964 and 1965 as a cooperative venture of the Navy Department and the Forest Service's Institute of Forest Genetics (King and Krugman 1980). Of 36 species, 6 or 7 were very promising (table 1), and if marketed for fuelwood or chips, would return at least 6.2 percent on investment (Standiford and Ledig, this volume).

PROVENANCE TESTS

The species trials of both the University of California and the Institute of Forest Genetics suffer from a common deficiency; neither took into account intraspecific genetic variation. Wide-ranging species are usually subdivided into populations adapted to the varying climatic and edaphic conditions in which they occur. While seeds from one area may produce rapidly growing trees under Californian conditions, seeds of the same species, but from other areas, may fail miserably. Species trials that only sample a single population may give misleading results. Species introductions should sample at least the extremes and center of the range.

A further problem is that neither the University nor the Institute included blue gum (E. globulus Labill.) in its species trials, so there is no direct comparison of California's most commonly planted eucalypt.

In 1975 a series of seed source, or provenance, tests were initiated to determine the range of genetic variation within species of greatest potential as indicated in the Institute's species trials. Provenances of five species are now under test. A provenance trial of blue gum is also planned because it often shows phenomenal growth in California, and its supremacy for biomass production is well established in world forestry.

River red gum

A seed source, or provenance, test of river red gum was begun in 1975. Seeds of 23 provenances were sown in June, the seedlings transplanted into Tinus containers, and then outplanted at Concord in February, 1976. Details of cultivation are reported by Emery and Ledig (in preparation). By the time the planting reached age 5.5 years, results were clear (table 2).

All the top six seed sources (A-F) come from the Murray and Darling River drainages and adjacent watersheds of Victoria, South Australia, and New South Wales. Statistical techniques that link areas of similar climate, tend to cluster these sources into one group (fig. 1). The area is characterized by relatively low rainfall, rather cool maximum temperatures, and a long season in which frost can occur (>120 days).

One seed source, from a dry lake bed, Lake Albacutya, Victoria, stood out. Its volume growth was 161 percent better than the average and 598 percent better than the worst seed source. Mean growth for the Lake Albacutya seed source was substantially better than growth of river red gum in the adjacent 1964-65 species trials. Diameter was 6.6 cm and height 6.2 m at 6 years in the species trial, but the Lake Albacutya source already exceeded that at 5.5 years: 9.5 cm and 7.2 m, respectively. We have

Table 2--Eucalyptus camaldulensis provenance means 5.5 years after planting.

Provenance	Volume[1] (cu m)	Height (m)	dbh (cm)	Straightness[2]
Lake Albacutya, Victoria	[3].0684 a	7.17 a	9.5 a	2.4 ghij
Hamilton, Victoria	.0570 ab	5.97 be	8.9 ab	2.6 efghij
Nathalia, Victoria	.0463 abc	5.78 bcd	7.8 abc	2.9 cdefg
Angaston, South Australia	.0462 abc	5.85 bcd	8.5 ab	2.4 ghij
Darlington Point, New South Wales	.0421 bcd	6.32 ab	7.6 abcd	2.6 efghij
Forbes, New South Wales	.0297 cde	5.40 bcde	7.2 bcde	2.5 efghij
Port Lincoln, South Australia	.0270 cde	4.94 cdef	7.1 bcde	2.1 j
Petford, Queensland	.0253 cde	5.99 be	6.2 cdef	3.2 be
Mundiwindi, Western Australia	.0230 cde	4.98 cdef	6.0 cdef	3.4 ab
Agnew (AR), Western Australia	.0224 cde	4.85 def	6.1 cdef	3.0 bcdef
Alice Springs (I), Northern Territory	.0215 cde	4.54 of	5.7 cdef	2.8 cdefgh
Onslow, Western Australia	.0201 de	4.36 of	6.0 cdef	2.5 fghij
Quilpie, Queensland	.0200 de	5.19 cdef	5.8 cdef	3.1 bcd
Pentland, Queensland	.0194 de	4.85 def	5.8 cdef	2.6 efghi
Hughenden, Queensland	.0191 de	4.79 def	5.8 cdef	2.8 cdefgh
Wiluma, Western Australia	.0180 de	4.99 cdef	5.5 cdef	3.8 a
Alice Springs (H), Northern Territory	.0173 de	4.89 def	5.3 of	3.0 bcde
Agnew (AO), Western Australia	.0170 de	4.82 def	5.5 def	2.9 cdef
Quilpie (P), Queensland	.0148 e	4.55 of	5.5 def	2.2 ij
Thargomindah, Queensland	.0146 e	4.18 f	5.1 of	2.3 hij
Three Springs, Western Australia	.0124 e	4.29 f	5.2 of	2.7 defgh
Katherine, Northern Territory	.0107 e	4.36 of	4.6 f	3.0 bcde
Newcastle Waters Creek, Northern Territory	.0098 e	4.14 f	4.3 f	2.7 defgh

[1]Estimated by dbh[2] x ht

[2]Scored from 1 = most crooked to 5 = straightest

[3]Means followed by the same letter do not differ significantly at the 5 percent probability level, according to Fisher's protected least-significant differences multiple range test

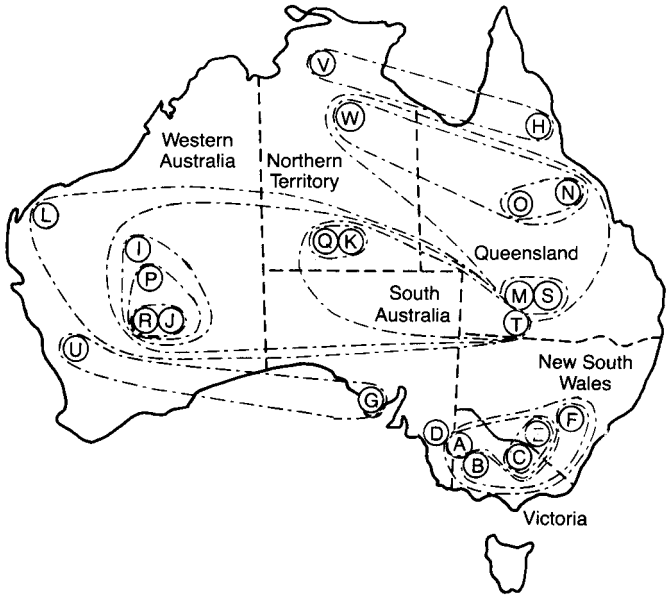

Figure 1--Location of Eucalyptus camaldulensis seed sources in Australia. Broken lines cluster seed sources of similar climate.

confidence in these results because the Lake Albacutya seed source has emerged superior wherever it was planted in a Mediterranean climate similar to California's; e.g., in Greece (Panetsos 1970), Israel (Karschon 1974; Moreshet 1981), Italy (Giordano 1974), Morocco (Destremau and others 1973), Rhodesia (Barrett and Carter 1976), Zambia, Spain, Algeria, and Portugal (Lacaze 1978). The Lake Albacutya source is also reported as highly salt tolerant (Sands 1981). It seems likely that this seed source will surpass any other previously planted in California. It should be able to withstand some cold and drought, as well as saline soils.

Flooded gum

Seed from 15 flooded gum sources (E. grandis Hill ex Maid.) was sown in September 1976, and outplanted at Concord in March 1978. Early results, at 3.25 years, show that there is less variation in flooded gum than in river red gum (table 3; Bailey and Ledig, in preparation). Nevertheless, the best seed source, Orara East in New South Wales, was 14 percent taller and had 32 percent greater volume than the plantation average.

Table 3--Eucalyptus grandis provenance means for relative volume, height, dbh, and straightness 3.4 years after planting.

Provenance	Volume (cu m)	Height (m)	dbh (cm)	Straightness[4]
Orara East	[3]0.041	[2]6.5 a	[3]7.5	[3]3.06
Tanban	0.039	6.4 ab	7.4	2.87
Newfoundland	0.037	6.3 ab	7.4	2.90
Tucker's Knob	0.041	6.1 abc	7.5	3.29
Pine Creek	0.033	6.1 abc	6.8	3.30
Orara West	0.032	6.0 abc	6.7	2.96
Yabbra	0.033	5.8 abcd	6.8	3.38
Newry	0.024	5.7 bcd	6.3	3.10
Wild Cattle Creek	0.035	5.4 cde	6.6	2.90
Lorne	0.026	5.3 cde	6.0	3.17
Nulla Five Day	0.021	5.1 de	5.5	3.14
Minmi	0.025	5.1 de	5.6	2.70
Queen's Lake	0.030	5.1 de	6.5	3.19
Brooloo	0.024	5.0 de	2.1	3.50
Bellinger River	0.019	4.8 e	5.1	2.61

[1]All provenances were from New South Wales except Brooloo, Queensland

[2]Means followed by the same letter do not differ significantly at the 5 percent level of probability, according to Fisher's protected least significant differences multiple range test

[3]Not statistically different among provenances

[4]Scored from 1 = most crooked to 5 = straightest

Despite the early age of the test, results can be viewed with some confidence. The same seed sources performed similarly in South African trials. The correlation between seed source height in South Africa and height in California was 0.72, and for dbh 0.79.

The relationships between climate at the seed source and growth in California were weak in flooded gum. There is a slight association of growth with longitude (r = 0.66), but it is of little help in indicating where to find superior provenances in Australia.

Shining gum

Shining gum (E. nitens Maid.) is not well-known in California. However, it grew well in the 1964-65 species trials at Concord and suffered almost no damage from the record freeze of 1972. Since it was first planted at Concord, provenance tests established in Australia (Pederick 1979) indicate that the seed source used in the Concord plantings is one of the most slow-growing, at least, under Australian conditions. By implication, the already excellent performance of shining gum at Concord can be improved upon with proper choice of seed source.

In 1982, 25 provenances of shining gum were planted at Concord. Similar tests were established near Ukiah in cooperation with Masonite Corporation. A third test near Santa Nella failed because it was planted late and did not receive necessary weed control or irrigation. It is much too early to draw any conclusions, but initial results after a year in the field suggest substantial differences among provenances (table 4).

Mountain gum and manna gum

The single most rapidly-growing eucalypt in the Concord species trial was mountain gum (E. dalrympleana Maid.). However, some of the trees in the test have leaves on basal sprouts that look more like manna gum (E. viminalis Labill.). It is possible that the seed supplied by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Forest Research in Australia was manna gum, a mixture of mountain and manna gum, or hybrids. The two species intergrade over an altitudinal gradient, and mountain gum could be merely the high elevational form of manna gum (Phillips and Reid 1980). We expect mountain gum to be more frost-hardy than manna gum because it occurs at higher elevations.

Because of the dubious taxonomic status of mountain and manna gums and the apparent ease with which they cross, it was decided

Table 4--Eucalyptus nitens provenance means for height and survival 1.3 years after planting.

Seed source and locality	Survival (pct)	Height (cm)
Rubicon, Victoria		
Tweed Spur	78	93.4
Snobs Creek	76	99.3
Barnewall Plain	78	81.5
Mt. Donna Buang	78	94.1
Toorongo, Victoria		
Toorongo Plateau	79	85.3
Upper Thomson	88	83.0
Marshall Spur	77	86.1
St. Gwinear	84	89.3
Mt. Erica	77	81.6
Mt. Toorongo	76	90.0
Tanjil Bren	68	94.6
Christmas Creek	75	81.9
Powelltown	92	90.7
Macalister, Victoria		
Mt. Skene	80	86.5
Connors Plain	85	86.9
Mt. Useful north	77	83.1
Mt. Useful south	85	90.8
Mt. Wellington	77	83.3
Errinundra, Victoria		
Errinundra north	84	102.4
Errinundra south	87	83.8
Goongerah	75	102.9
Southern New South Wales		
Nimmitabel	75	68.4
Tallaganda	83	70.2
Northern New South Wales		
Ebor	58	65.0

to include both forms in provenance trials. A trial of six provenances of mountain gum and two of manna gum was started earlier this year, 1983. Plantings were made at Concord, near Anderson in northern California, near Standard in the foothills of the Sierra Nevada, and at Santa Nella. It is much too early to tell whether these plantations will succeed, but the range of planting sites should provide a good test of adaptability. Subfreezing weather cannot be counted on at Concord each year; the Anderson and Standard sites will be more likely to provide a test of cold hardiness. The Santa Nella site will provide a test of tolerance for soil salinity.

Blue gum

Blue gum is a rapidly growing tree with some cold tolerance. However, the commonly planted ssp. globulus suffered badly during the freeze of 1972. Large trees in the Berkeley Hills were killed back to their base. Subspecies maidenii and bicostata are considered more cold-hardy than ssp. globulus. These subspecies, along with ssp. pseudoglobulus, were formerly considered separate species from blue gum (Kirkpatrick 1974). The Australian Division of Forest Research (CSIRO) provided seed of 35 provenances of blue gum, including all its subspecies, and these will be field planted in 1985.

Other considerations

For species already provenance tested, large plot tests of the best seed sources should be established in several locations to judge their breadth of adaptability and to develop data on growth and yield. Tests of container methods, planting time and technique, and spacing are also needed to develop more effective systems of production. Other eucalypts that may be provenance tested include tingiring gum (E. glaucescens maid. and Blakeley) and swamp gum (E. ovata Labill.).

SELECTION AND BREEDING

To cover the wide variety of site and climatic conditions in California, it is likely that more than one eucalypt species will be used. Once superior provenances are identified, seed can be purchased from Australian seed dealers. But even greater growth and adaptability can be obtained by selecting and breeding eucalypts specifically for California. There is enough genetic variation within the commonly used species that we always find some outstanding individual trees even within the best provenances.

To capitalize on such variation requires selection of superior trees. The Institute of Forest Genetics has begun to select superior phenotypes in older plantations in California and in our own provenance tests at Concord. Trees in the older plantations have undergone one generation of selection under California conditions and have demonstrated their ability to withstand drought and cold. They constitute "land races." However, in an exotic species, there are limited possibilities for selection because the number of trees available is small.

Other eucalypt breeding programs, domestic and foreign, are another source of breeding material. The eucalypt breeding program in Florida has 40 clones of river red gum which should be tested in California. Perhaps even more valuable are selections of drought and saline tolerant

eucalypts made by the Agricultural Research Organization, Israel and by agencies in India. The Institute of Forest Genetics is proposing collaborative projects with both Israeli and Indian tree breeders working with fuel biomass programs.

Once superior individuals are selected, there are two approaches to produce improved planting stock; i.e., through seed production in seed orchards or by mass production of rooted cuttings. In seed orchards, selected trees are brought together, as grafted or rooted clones, and allowed to cross-pollinate. Eucalypts flower at an early age so seed orchards will produce commercial quantities of seed in a very few years. If selection has been effective, the seed should produce superior progeny. The alternative is to clone the selected individuals and use them directly, perhaps as rooted cuttings. While clonal production is more expensive than seed production, it also offers the possibility of greater immediate gains. Techniques for vegetative propagation are discussed by Boulay and Chaperon in this volume. Whatever the approach, seedling or clonal, the next step in eucalypt culture in California is to establish sources for superior planting materials, and it is likely to require a cooperative commitment between growers and the State and Federal governments.

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