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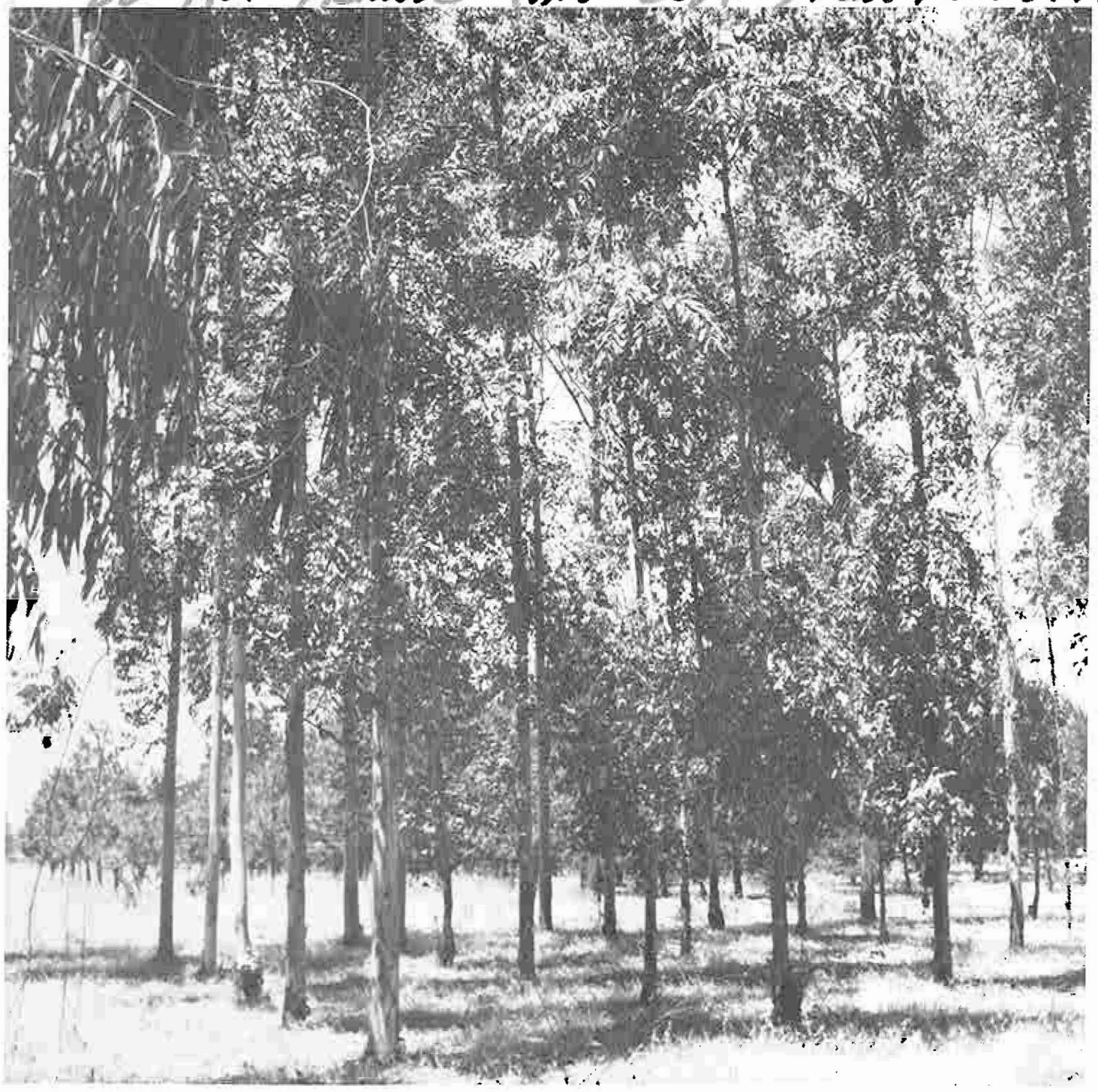
Tests of 36 *Eucalyptus* Species in Northern California

James P. King Stanley L. Krugman



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IN BRIEF...

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Retrieval terms: *Eucalyptus*, species trial, California, eucalypts

The purpose of this study was to compare and identify appropriate species of *Eucalyptus* suitable for planting on low-elevation sites in central California.

Australian foresters selected 36 *Eucalyptus* species on the basis of potential cold-hardiness and tree form, and provided us with general area seed collections. Some attempt was made to collect seed from the higher elevations of most species.

A test plantation was established in cooperation with the U.S. Navy near Concord, California, about 20 miles inland from San Francisco Bay. The site is on good agricultural soil and has the hot, dry summer, and cool, moist winters typical of California's central valley. A record-breaking cold spell occurred in the area in the winters of 1972-73, when the oldest trees were still less than 10 years of age.

Thirty-one species were field-planted in 1965, using 10-month-old containerized seedlings. Replanting of fail spots was done in 1966 and a thirty-second species added. In 1968, four additional species were planted.

Of the 36 species tried, 21 were regarded as outright failures. The 21 failure species included all 10 of the species from western Australia and 10 of the 11 *Monocalyptus* species included in the study. In general, the higher elevation collections from eastern Australia were best in terms of survival and growth rate.

The seven highest rated species were: *Eucalyptus camaldulensis*, *E. dalrympleana*, *E. glaucescens*, *E. grandis*, *E. nitens*, *E. ovata*, and *E. viminalis*. These species all had high survival, made good growth, and readily recovered from the record-breaking 1972 freeze.

The study re-emphasized to us the sensitivity of *Eucalyptus* to competition, particularly on this summer-drought site. The interplanted trees, though only 1 year younger than the original planting, were suppressed throughout the entire course of the study and rendered area volume estimates useless.

In 1964, the Forest Service's Pacific Southwest Forest and Range Experiment Station and the Navy's Concord Naval Weapons Station joined in a cooperative study of 36 *Eucalyptus* species. The study was to compare and identify appropriate species that would be suitable for planting on low elevation and similar areas in California. The Navy's interest in such plantation trials stemmed from its desire to better utilize the land under its jurisdiction.

The species tested at Concord, about 20 miles northeast of San Francisco, were to be evaluated primarily for their ability to produce wood products, such as posts, bumper piles, pallets, and timber, and for their potential for wood chips, firewood, and values as wildlife habitat and landscaping. Among the more than 500 *Eucalyptus* species, a number have been tried at numerous sites throughout California, but relatively few have been successful (Metcalf 1961, 1967).

In the first trials, 36 *Eucalyptus* species were selected and obtained from Australia *(table 1)*. Dr. M. R. Jacobs, then Director-General of the Forestry and Timber Bureau of Australia, and the late E. Larsen, of the same organization, made initial recommendations in selecting species and assisted in obtaining the seeds for this study. Species were selected on the basis of potential cold hardiness and tree form. These seed collections usually represented general area collections, although some attempt was made to collect from the highest elevations of most species.

This paper reports results of early survival, growth, flowering and cold resistance.

SITE CHARACTERISTICS

Although the Concord, California, site is within 20 miles of San Francisco Bay, the presence of a range of low hills west of the test site makes the climate more closely related to inland areas. That is, the climate at the site more closely resembles Sacramento than coastal San Francisco.

Mean monthly temperatures range from 43°F (6°C) in January to 73°F (23°C) in July. From 1965 to 1977, temperatures reached over 100°F (38°C) in every summer but one, while the coldest winter temperature reached between 20°F (−7°C) and 25°F (−4°C). A recordbreaking cold spell occurred in December 1972 when temperatures dropped below 32°F (0°C) on nine consecutive nights; the lowest temperature occurred on December 11, when 16°F (−9°C) was recorded. A second cold wave occurred in late December and early January 1973, when the temperature went below freezing on 10 consecutive nights, with a low of 20°F (−7°C) on January 7. Rainfall ranges from 2 inches (51 mm), from April through September, up to 19 inches (508 mm) from October through March. Elevation of the planting site is 204 feet (61.8 m). Soils at the Concord test site are variable but tend to be well-drained sandy loams of excellent agricultural quality.

PROPAGATION AND SURVIVAL

In the initial test series, in May 1964, the seeds of 32 species were sown in flats in the greenhouse at the Station's Institute of Forest Genetics, Placerville, California. Germination was generally good except for *Eucalyptus camaldulensis* and *E. delegatensis*. Once the seedlings had developed two pairs of leaves, they were transplanted into individual plant bands. In later studies, all seeds were stratified for at least 30 days at 41°F (5°C). Such treatment improved both the rate and percentage of seed germination.

Because of differential growth rates between various species, it was necessary to top-prune the faster growing seedlings at least once before field planting. The seedlings (hereafter called the 1964 seedlings) were held in the greenhouse until danger of late spring frost passed in early 1965, after which they were field planted on a prepared site.

The plantation site was disked twice during summer and fall 1964 to reduce weed competition, particularly wild oats and star thistle. The seedlings were planted at 10-foot (3-m) spacing using a soil auger to drill the planting holes. The planting was laid out in three blocks of 32 plots each. Not enough *E. camaldulensis* were available so only 31 plots per block were planted. Each plot contained 16 trees of the same species planted in 4 rows, 4 trees per row. The trees were planted on February 24 and 25. Two months later, April 22, average survival for all species was 72 percent. Irrigation of these seedlings was planned for the first two summers following field planting, but a delay in receiving and installing an irrigation system left the seedlings without water until mid-June. When the second

survival count was taken on June 22, survival averaged 33 percent. The third survival count taken on October 11 showed average survival to be 30 percent. By 1968, 15.5 percent of the trees planted were alive. Only four of the 32 species had more than 50 percent survival—*E. melliodora, E. dalrympleana, E. nitens,* and *E. viminalis (table 1).* The seeds of the last three of these species were from elevations above 2900 feet (884 m) in eastern Australia.

In fall 1965, replacement seedlings of 31 species (hereafter called the 1965 seedlings) were grown in the greenhouse at Placerville. They were field planted in April 1966 in the same spots where the 1964 seedlings died. Irrigation was started immedi-

Table 1—*Survival of 36 species of Eucalyptus planted at Concord, California*

Species	Location	Elevation	1964 seedlings						1965 seedlings					
			Planted	Alive					Planted	Alive				
			1965	1968	1971	1972	1974	1977	1966	1968	1971	1972	1974	1977
		m												
			Good survival and growth											
E. camaldulensis Dehn.	Victoria	—	0	0	0	0	0	0	48	42	42	42	32	31
E. dalrympleana Maiden	New S. Wales	975	48	31	31	31	31	31	15	14	12	12	10	9
E. glaucescens Maiden and Blakely	Victoria	1067	48	17	17	17	17	17	29	25	23	23	21	21
E. grandis Hill ex Maiden	New S. Wales	—	48	8	8	8	6	6	34	33	33	33	30	31
E. nitens Maiden	Victoria	884	48	29	29	29	26	26	17	17	17	17	17	16
E. ovata Labill.	Tasmania	—	48	18	18	18	14	14	29	14	11	9	7	7
E. viminalis Labill.	New S. Wales	1219	48	41	41	41	41	40	8	8	7	6	6	6
			Good survival											
E. behriana F.v.M.	Victoria	198	32	0	0	0	0	0	48	26	14	14	14	14
E. coccifera Hook	Tasmania	—	48	1	0	0	0	0	47	32	24		19	19
E. fruticetorum F.v.M.	Victoria	—	46	5	[1] 6		11	11	35	30	19		13	15
E. melliodora A. Cunn.	New S. Wales	137	48	25	[1]21		28	29	19	21	25		16	16
E. resinifera Sm.	New S. Wales	24	48	11	[1]18	18	16	11	25	21	21		16	15
E. robusta Sm.	New S. Wales	—	48	8	[1]13		11	11	31	31	27		20	20
E. polyanthemos Schau.	Victoria	305	[2]	[2]	[2]	[2]				48			40	40
E. sideroxylon A. Cunn. ex. Woolls.	Victoria	259	[2]	[2]	[2]	[2]				48			35	29
			Failures											
E. andrewsi Maiden	New S. Wales	762	[2]	[2]	[2]	[2]				48			8	4
E. fastigata Deane and Maiden	New S. Wales	—	48	11	8		4	0	28	27	16		9	8
E. niphophila Maiden and Blakely	New S. Wales	—	39	9	8		6	1	37	17	14		10	6
E. obliqua L'Herit.	New S. Wales	61	48	0	0		0	0	47	34	20		18	2
E. pauciflora Sieb. ex Spreng.	Cap. Terr.	1341	48	2	1		0	0	46	16	12		8	4
E. radiata Sieb. ex DC.	New S. Wales	853	[2]	[2]	[2]	[2]				48			14	7
E. regnans F. Muell.	Tasmania	335-549	48	2	2		0	0	43	38	25		8	4
E. stellulata Sieb. ex DC.	Victoria	762	48	13	12		11	5	33	31	17		15	6
E. transcontinentalis Maiden	West. Aust.	—	48	0	0		0	0	48	19	11		5	3
E. oleosa F.v.M.	West. Aust.	—	47	0	0		0	0	47	15	1		2	1
E. robertsoni Blakely	Cap. Terr.	—	47	6	6		0	0	38	18	5		1	0
E. salmonophloia F. Muell.	West. Aust.	—	28	0	0		0	0	48	18	2		2	1
E. brockwayi C. A. Gardn.	West. Aust.	—	48	0	[3]	[3]	[3]		47	9	[3]	[3]	[3]	
E. calophylla R. Br.	West. Aust.	—	48	0	[3]	[3]	[3]							
E. delegatensis R.T. Bak.	Cap. Terr.	—	48	3	[3]	[3]	[3]		27	2	[3]	[3]	[3]	
E. diversicolor F.v.M.	West. Aust.	—	48	0	[3]	[3]	[3]		—		[3]	[3]	[3]	
E. dundasi Maiden	West. Aust.	—	48	0	[3]	[3]	[3]		48		[3]	[3]	[3]	
E. gomphocephala A. DC.	West. Aust.	—	48	0	[3]	[3]	[3]		8	8	[3]	[3]	[3]	
E. polycarpa F.v.M.	North. Terr.	—	48	0	[3]	[3]	[3]		44	0	[3]	[3]	[3]	
E. redunca var. elata Benth.	West. Aust.	—	45	0	[3]	[3]	[3]		30	1	[3]	[3]	[3]	
E. torquata Luehm.	West. Aust.	—	44	0	[3]	[3]	[3]		30	1	[3]	[3]	[3]	

[1]Additional seedlings planted in 1969.
[2]Planted only in 1968.
[3]Discontinued in 1968.

ately after planting, and early survival was very good. Two years following planting, the 1965 seedlings had 50 percent survival. Sixteen of the 31 species had better than 50 percent survival. In June 1966, 82 percent of all the spots in the plantation had living seedlings. In early 1970, four additional *Eucalyptus* species were field planted in plots where other species had failed. In spring 1968, irrigation was stopped on the 3- and 4-year-old eucalypts.

RESULTS

In the discussion of the trials, the differences reported are not necessarily statistically significant. Because of problems in setting up the trials, the tests of significance were not considered reliable.

Of the 36 species planted, nine species had negligible survival at 2 and 3 years *(table 1)*. Most of the mortality among 1964 seedlings was related to drought damage as well as weed competition. For the 1965 seedlings, frost damage appeared to be the most significant factor, but weed competition remained a serious problem. The nine completely unsuccessful species were:

E. brockwayi
E. delegatensis
E. diversicolor
E. dundasi
E. gomphocephala
E. polycarpa
E. redunca var. elata
E. torquata
E. calophylla (tried in 1964 only)

Three other species—*E. oleosa, E. robertsoni,* and *E. salmonophloia*—had very few survivors in the 1964 planting, and some success in the 1965 planting. After five seasons in the field, these species were practically eliminated by repeated frosts.

A third group consisting of nine species had fair to good early survival but has suffered a consistent mortality rate that indicates lack of adaptation to climatic conditions at the site. These species are:

E. andrewsi
E. fastigata
E. niphophila
E. obliqua
E. pauciflora
E. radiata
E. regnans
E. stellulata
E. transcontinentalis

Only one species, *E. regnans,* showed a sharp increase in mortality that could clearly be associated with recordbreaking low temperatures that occurred in December 1972.

Eight species showed good survival, the ability to tolerate drought, and recover from the 1972 freeze, but must be considered too slow-growing for use outside of landscaping:

E. behriana
E. coccifera
E. fruticetorum
E. melliodora
E. polyanthemos
E. resinifera
E. robusta
E. sideroxylon

The seven species showing the most potential in terms of survival and growth rate *(fig. 1)* are:

E. camaldulensis
E. dalrympleana
E. glaucescens
E. grandis
E. nitens
E. ovata
E. viminalis

E. ovata is somewhat borderline. While its growth has been the best in this group, its survival and form are the poorest.

Growth Rate

Of the 11 fastest-growing species, *E. camaldulensis, E. glaucescens, E. grandis, E. nitens,* and *E. ovata* are clearly among the best in terms of height, diameter, and tree volume *(table 2)*. *E. dalrympleana* and *E. viminalis* did well but seem highly inconsistent between the 1964 and 1965 seedlings. This inconsistency can be explained largely by the fact that the 1964 seedlings of *E. dalrympleana* and *E. viminalis* had high survival in 1965. Therefore, the trees planted in 1966 were interplanted in fairly well-stocked plots and were strongly suppressed by the 1964 seedlings.

The large growth variable between the 1964 and 1965 trees of almost all the other species is difficult to explain. The differences between the two plantings are much greater than can be accounted for by a single year's growth. The 1964 planted trees did receive an additional year of irrigation.

Partly because of the additional irrigation in 1964 and therefore faster establishment, and partly because of the suppression effect of the 1964 trees on the 1965 trees, the 1965 trees have less than half

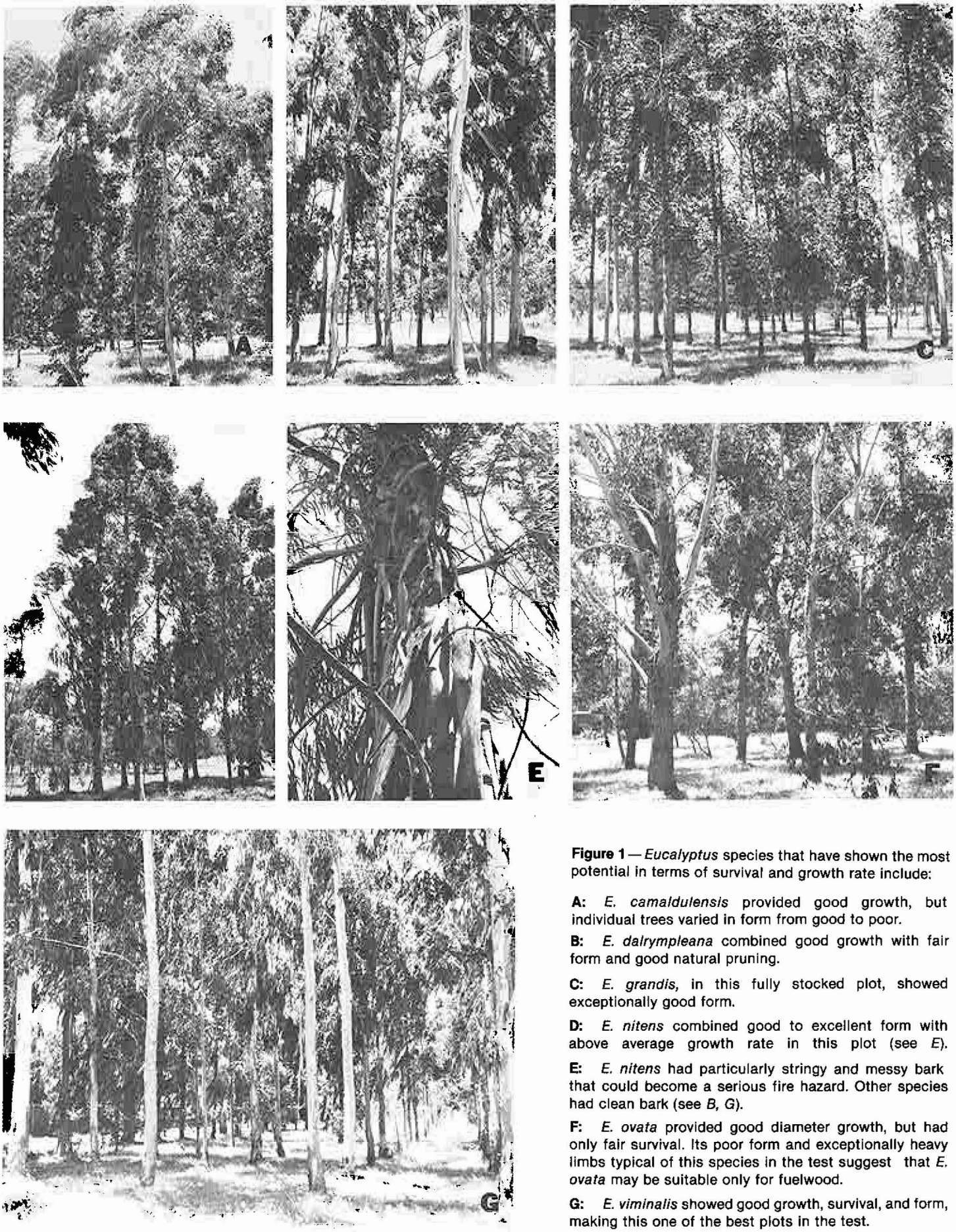

Figure 1 — *Eucalyptus* species that have shown the most potential in terms of survival and growth rate include:

A: *E. camaldulensis* provided good growth, but individual trees varied in form from good to poor.

B: *E. dalrympleana* combined good growth with fair form and good natural pruning.

C: *E. grandis,* in this fully stocked plot, showed exceptionally good form.

D: *E. nitens* combined good to excellent form with above average growth rate in this plot (see *E*).

E: *E. nitens* had particularly stringy and messy bark that could become a serious fire hazard. Other species had clean bark (see *B, G*).

F: *E. ovata* provided good diameter growth, but had only fair survival. Its poor form and exceptionally heavy limbs typical of this species in the test suggest that *E. ovata* may be suitable only for fuelwood.

G: *E. viminalis* showed good growth, survival, and form, making this one of the best plots in the test.

Table 2—*Growth of the 11 fastest growing Eucalyptus species at Concord, California*

Species	1964 seedlings								1965 seedlings							
	1968	1971		1974		1977			1968	1971		1974		1977		
	Ht.	Ht.	D.b.h.	Ht.	D.b.h.	Ht.	D.b.h.	Vol/ tree	Ht.	Ht.	D.b.h.	Ht.	D.b.h.	Ht.	D.b.h.	Vol/ tree
	m	*m*	*Cm*	*m*	*Cm*	*m*	*Cm*	*Cu m*[1]	*m*	*m*	*Cm*	*m*	*Cm*	*m*	*Cm*	*Cu m*[1]
E. camaldulensis									2.74	6.21	6.6	9.08	10.4	10.06	12.4	.06
E. dalrympleana	7.77	14.11	16.5	15.45	20.8	17.22	22.4	.29	1.80	5.40	5.1	7.35	8.4	8.08	8.9	.02
E. glaucescens	3.96	9.45	11.9	12.07	16.8	13.35	17.8	.15	1.59	5.61	5.1	8.63	8.9	9.75	9.9	.03
E. grandis	4.63	8.96	10.7	13.53	17.5	15.33	19.3	.20	2.56	8.14	7.9	10.76	12.2	11.58	12.7	.07
E. nitens	4.88	9.05	13.2	12.80	18.5	13.81	19.8	.19	1.98	7.53	8.4	11.52	13.7	13.17	16.8	.13
E. ovata	6.61	11.46	15.2	14.63	22.9	13.84	24.1	.28	1.62	5.61	7.1	10.58	14.5	11.77	16.0	.10
E. viminalis	5.67	10.45	12.2	13.50	15.7	14.11	17.0	.14	1.71	4.97	4.3	8.38	7.4	9.11	7.9	.02
E. melliodora	2.19	6.10	6.9	8.26	10.4	9.20	11.7	.04	0.91	4.27	4.8	6.37	6.9	7.80	8.4	.02
E. regnans		5.58	4.1						1.19	4.66	3.6	5.94	6.4	10.30	10.9	.04
E. resinifera	2.99	6.16	6.9	6.80	9.9	8.53	11.7	.04	1.40	4.51	4.6	5.79	8.4	6.80	10.4	.03
E. robusta	3.11	6.28	8.6	7.32	12.7	7.65	11.9	.04	1.62	4.54	2.5	5.88	9.4	6.40	9.7	.02

[1]Volume equation derived from data in Metcalf (1924). Stem volume including bark to a 2-inch (15 cm) top. Volume (cubic feet) = 0.00245 (diameter^2 [inches]) (height [feet]) −0.3318. Volume then converted from cubic feet to cubic meters using 1 cubic foot = .02832 m^3.

the volume of the 1964 trees, even after adjusting for age differences. Moreover, the volume differences between 1964 and 1965 trees are getting larger.

Flowering

With the obvious exception of nonsurviving species, all species flowered within 8 years following field planting. Several of the faster-growing species flowered by age 5, including:

E. behriana
E. camaldulensis
E. fruticetorum
E. grandis
E. melliodora
E. resinifera
E. robusta
E. transcontinentalis

Of the 22 species observed at the Concord plantation, variability was evidenced not only in the rate of maturity to first flowering, but also in the time of year when the flowering season occurs *(table 3)*.

1972 Freeze

The very low temperatures that occurred during December and January 1972-73 caused severe damage to many *Eucalyptus* groves in the Bay Area. In the Concord planting, obvious differences between species could be seen in the percent of foliage damaged by the cold. The slower-growing species generally had the most damage. *E. regnans, E. resinifera,* and *E. robusta,* had more than 80 percent of their foliage damaged. *E. camaldulensis, E. dalrympleana, E. glaucescens, E. nitens,* and *E. viminalis* had less than 20 percent of their foliage damaged. *E. grandis* and *E. ovata,* though among

Table 3—*Flowering, fruiting, and seed dispersal seasons of Eucalyptus species*

Species	Seasons		
	Flowering	Fruit ripening	Seed dispersal
E. behriana	Feb-Apr	—	—
E. camaldulensis	Feb-Apr	July-Oct	Commences 8 to 9 months after flowering
E. coccifera	May-June	—	—
E. dalrympleana	June-Aug	Aug-Oct	Oct-Nov
E. delegatensis	Apr-June	Apr-June	May-July
E. fastigata	Apr-May	July-Aug	—
E. fructicetorum	June-Sept	—	—
E. glaucescens	July-Aug	May-Sept	Nov-Feb
E. grandis	Sept-Nov	—	—
E. melliodora	Feb-July	—	—
E. niphophila	Mar-Apr	—	—
E. nitens	Apr-July	May-June	May-June
E. obliqua	Apr-July	May-Aug	—
E. ovata	July-Dec	—	—
E. pauciflora	Mar-May	—	—
E. regnans	Apr-July	June-Sept	—
E. resinifera	Mar-May	—	—
E. robusta	Jan-Mar	—	—
E. sideroxylon	June-Sept	—	—
E. stellulata	July-Nov	—	—
E. transcontinentalis	Jan-Nov	—	—
E. viminalis	All year	12 months after flowering	20 to 22 months after flowering

the faster growing, had moderate (50 to 70 percent) damage to their foliage.

Most of the species showed good ability to recover from the freeze damage. Only *E. regnans* showed an increase in mortality that could be associated with the freeze. Thus, the 1972 freeze provided strong indication that the faster-growing species, when old enough, could withstand even the coldest Bay Area weather.

DISCUSSION

Pryor (1976, p. 76) has pointed out that, with few exceptions, species of the subgenus *Monocalyptus* seldom do well outside Australia. He suggested that such failure by this group could be due to a lack of suitable mycorrhizal fungus in exotic plantations. Pryor (1976, p. 4) also pointed out that a major difference exists in species distribution between southwestern and southeastern Australia that seems independent of climate. A most striking feature of the present data is that the 21 species regarded as failures in this study include all 10 of the western Australian species and 10 of the 11 *Monocalyptus* species. *E. coccifera* was the only *Monocalyptus* that survived well here. No serious damage from disease or insects was noted during the course of this study.

Growth data were not subject to an analysis of variance, for several reasons. To determine that one species was significantly faster-growing than another on the basis of this data would be highly misleading. Most species were represented by general seed collections. Thus, any analysis would have to ignore variation within each species. There might be other seed sources within a slow-growing species that could outgrow the general collections used in this study.

Moreover, the sprouting habit of *Eucalyptus* adds an additional and unquantifiable variation to growth measurements. In a number of instances, individual trees "died" while young but immediately stump-sprouted. The sprouts initially grew much faster than the original stem but eventually slowed to a more "normal" growth rate. Under these circumstances, it is very difficult to define or determine normal volume.

Our experience in this and newer studies has reemphasized the sensitivity of *Eucalyptus* to cultural practices, particularly weed control. Part of a newly planted *E. camaldulensis* provenance study at the Concord site was established on soil that was disked and maintained weed-free for two growing seasons prior to planting. The remaining trees in the test were planted in an adjacent area that was cleared of weeds immediately before planting. All trees were hand watered and maintained free of weed competition for 18 months following planting. The trees in the newly cleared area averaged just under half the height of the trees in the twice-cleared area—2.99 feet to 6.03 feet (0.91 m to 1.84 m). Overall survival was over 92 percent. Thorough weed control is essential in establishing *Eucalyptus* plantations. Interplanting *Eucalyptus* in an established stand, even when very young, is not recommended. The results of this initial trial were confounded by competition between established trees and young seedlings, and suppression of the 1965 seedlings has continued.

In general, the higher elevation collections from eastern Australia did the best in terms of survival and rate of growth, while the lower elevation collections did the poorest. *E. grandis* was an exception. This species is closely related to *E. saligna* and is usually found on lower slopes or alluvial flats (Rodger 1953). Nevertheless, in tests at Canberra, (which is outside its natural range), *E. grandis* has shown resistance to temperatures lower than would occur within its natural range (Rodger 1953).

Greater effort is being taken to ensure that a wider selection of known seed sources be included in future tests. We have begun studies of variation within the faster-growing species. *E. camaldulensis* and *E. grandis* provenance tests are in progress. *E. viminalis, E. dalrympleana,* and *E. globulus* studies are needed.

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A trial of 36 species of *Eucalyptus* near Concord, California, found species of sufficiently rapid growth and good survival to merit further screening. Species from western Australia and of the subgenus *Monocalyptus* all failed on the site. *E. camaldulensis*, *E. dalrympleana*, *E. glaucescens*, *E. grandis*, *E. nitens*, *E. ovata*, and *E. viminalis* were the species with best survival and growth.

Retrieval terms: Eucalyptus, species trial, California, eucalypts