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Performance of Australian Provenances of *Eucalyptus grandis* and *Eucalyptus saligna* in Hawaii

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CONTENTS

IN BRIEF . . .

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Eucalyptus grandis trees grown from seed collected at four locations in Australia grew sufficiently better than trees grown from seed from 18 other locations when planted at four different sites on the island of Hawaii that it is recommended that seed of this species from these locations be used for future plantings on similar sites.

Both *E. grandis* and *E. saligna* have been grown in Hawaii for many years, but no records had been made of where the original seed introductions had been made in Australia, or how the different seed lots introduced performed when used in Hawaii. The tests reported here were conducted to determine what locations in the range of the two species in Australia were likely to supply seed that would provide trees best adapted to certain sites on the island of Hawaii where extensive future planting was contemplated.

Twenty-two seed lots were tested, 11 of each species, One *E. saligna* was a local collection, the rest were standard provenance collections made by the Commonwealth Scientific and Industrial Research Organization in Australia. The collections represented the complete latitudinal range and a broad elevational range of the species. Four tests were installed as complete randomized blocks, two in 1979 and two in 1981. The results reported are of 4 to 5 year-old trees.

At all four sites, most *E. grandis* provenances outgrew most *E. saligna,* but correlation was weak between latitude of the provenance (adjusted for elevation) and growth. Although the growth of the better performing provenances was not statistically significant from the growth of the average performers, certain of the provenances were consistently good performers at all four sites. It is therefore recommended that seed be collected from the best trees growing at the locations in Australia where the provenance collections were made for use in planting sites similar to those of these tests.

INTRODUCTION

Eucalyptus trees of several species were first introduced to Hawaii in the mid 1860's. More than 90 additional species have since been tried. Most of these species have been quite successful and are planted in large blocks in the forest rather than as individuals in arboreta. An early introduction was *Eucalyptus saligna* which, as in South Africa and Brazil, was imported long before *E. grandis* was recognized as a separate species. Some of the *E. saligna* was actually the taxon which in 1918 was separated from *E. saligna* and named *E. grandis* (Food and Agriculture Organization 1979). The two hybridized to some extent, but most specimens in Hawaii have the characteristics of *E. saligna*. Since the early 1960's, *E. saligna* has been the species most frequently used for new plantations. Almost all new plantings have been from local seed sources. Although about 6500 ha (15,000 acres) of *E. saligna* and about 50 ha (124 acres) of *E. grandis* exist today, seed source performance information is lacking for both species in Hawaii. We report here the first tests of possible better seed sources of the two species involved.

The need for provenance testing had been recognized for years, so provenance tests were among the first studies started by BioEnergy Development Corporation, a cooperative project of C. Brewer and Co. Ltd., the U.S. Department of Energy, and the USDA Forest Service in 1979. Initially, identical designs of 11 seed lots each of *E. saligna* and *E. grandis* from Australia were planted at two different sites. Later, in 1981, two additional tests of the same seed lots were planted at two other sites.

The parameters for rating the provenances were growth rate as expressed by diameter and height, survival as expressed by basal area per plot, wood density, coppicing ability, and ability of sprout cuttings to strike roots. The last characteristic will be important if a change from seedling to clonal plantations is made in the future.

This paper reports results of the first tests of possible better seed sources of *E. grandis* and *E. saligna* at four sites on the island of Hawaii. Worldwide, *E. grandis* has been planted more extensively than *E. saligna* and therefore has been the subject of more provenance testing (Food and Agriculture Organization 1979). One study from the Republic of South Africa consists of both *E. grandis* and *E. saligna* planted on five different sites (Darrow 1983). This study includes three of the seed lots used in the tests in Hawaii. In general, the South Africa study has shown that *E. grandis* is superior to *E. saligna* in growth and form on all sites, but that the better *E. saligna* provenances are nearly equal to *E. grandis* in biomass production because of higher wood density. At two of the sites with a temperate climate, *E. saligna* more nearly approached *E. grandis* in mean annual increment; whereas, at three subtropical sites, *E. grandis* frequently grew two to three times as fast as *E. saligna*. These results are consistent with the silvical requirements of the two species presented in the world literature (Food and Agriculture Organization 1979).

PROVENANCES

With the exception of one local collection (*E. saligna* No. 305), the seed lots used in Hawaii were provenance collections made by the Commonwealth Scientific and Industrial Research Organization of Australia, from average trees growing at distinctive locations *(table 1)*. The provenance collections were chosen for this study to represent the latitudinal and, to the extent possible, elevational ranges of the two species in Australia. The local collection was from several felled trees in a 45-year-old stand on the Hamakua Coast on the island of Hawaii. The island of Hawaii lies at latitude 19°30'N and 155°30'W.

SITES

Four sites were planted: Akaka, Upper Ninole, Lower Ninole, and Kamae. The Akaka site was a former sugarcane field which had lain fallow for several months before being sprayed with paraquat and then harrowed to prepare it for tree planting. It is a very wet location at 480 m (1600 ft) elevation with an evenly distributed rainfall of 5600 mm (220 in). The sky is usually overcast and the soil is frequently saturated by heavy rain despite rapid drainage. The soil, classified as Akaka silty clay loam (Thixotropic isomesic typic Hydrandept), is strongly acid (pH 5.5). The 15 percent slope faces northeast.

Upper Ninole was in sugarcane until a month before planting. The cane was killed with paraquat then crushed with a roller pulled by a tractor. At planting, the thick layer of rotting cane stalks served as a mulch that suppressed weeds and augmented site fertility. The planting site, which is flat, is at 540 m (1800 ft) elevation. Annual rainfall (winter high

Table 1—*Seed lots of* Eucalyptus grandis *and* E. saligna *planted in provenance or progeny tests, island of Hawaii*

Seed lot number	Supplier	Location	Latitude	Longitude	Elevation	Total mother trees
			° 'S	° 'E	*m*	
			Eucalyptus grandis			
[1]7810	CSIRO	Bulahdelah, NSW	32°20′	152°13′	120	11
[1]7823	CSIRO	Coffs Harbour, NSW	30°10′	153°08′	18	12
[1]11243	CSIRO	Tyalgum, NSW	28°27′	153°12′	100	4
[1]10774	CSIRO	E. of Gympie, Qld	26°14′	152°47′	400	6
[1]12143	CSIRO	Crediton, Qld	21°09′	148°30′	730	9
[1]12461	CSIRO	W. Paluma, Qld	19°00′	146°00′	900	—
[1]11035	CSIRO	NW of Cardwell, Qld	18°08′	145°37′	600	4
[1]12409	CSIRO	Ravenshoe area, Qld	17°42′	145°28′	940	26
[1]12381	CSIRO	Wondecla area, Qld	17°25′	145°27′	1010	13
[1]12422	CSIRO	SFR310 Gadgarra, Qld	17°16′	145°42′	690	20
[1]12423	CSIRO	Tinaroo Falls Dam, Qld	17°11′	145°36′	800	13
			Eucalyptus saligna			
[1]7786	CSIRO	Windsor, NSW	32°55′	159°33′	300	12
[1]10225	CSIRO	Cessnock, NSW	32°54′	151°24′	300	8
[1]10733	CSIRO	Raymond Terrace, NSW	32°42′	151°43′	9	—
[1]7808	CSIRO	Bulahdelah, NSW	32°20′	152°12′	210	12
[1]11605	CSIRO	N. Raymond Terrace, NSW	31°55′	151°48′	225	39
[1]11894	CSIRO	Gladfield, Qld	28°00′	152°23′	1020	—
[1]11756	CSIRO	Clifford, Qld	28°30′	151°50′	240	—
[1]12145	CSIRO	Connondale, Qld	26°44′	152°31′	600	—
[1]12064	CSIRO	S of Calliope, Qld	24°23′	151°00′	800	1
[1]11025	CSIRO	W of Rockhampton, Qld	23°49′	149°03′	860	4
[2]0305	B.D.C.	Hilo Forest Reserve, HI	19°55′N	155°15′W	540	—

[1]Collection numbers of Commonwealth Scientific and Industrial Research Organization, Canberra.
[2]Collection number of U.S. Forest Service, Honolulu.

distribution) averages 1850 mm (73 in). The soil is a rapidly drained Alapai extremely stony silty clay loam (Thixotropic isothermic typic Hydrandept), with a medium acid pH of 5.6 to 5.9.

Lower Ninole was cleared by harvesting the sugarcane shortly before planting. The rhizomes were plowed up and killed with herbicide, after which the remnants were rolled down. The site is at 370 m (1200 ft). Rainfall is about 1800 mm (71 in). The soil is Kiloa extremely stony muck (Euic isothermic typic Tropofolist), with a pH of 5.6 to 5.7 and very rapid drainage. Planting was difficult at this site because of the extreme stoniness.

Kamae is a wet, cloudy, imperfectly drained site at 550 m (1800 ft) on the Hamakua Coast. Rainfall is about 5000 mm (200 in), evenly distributed throughout the year. The soil is classified as Akaka series, but has numerous wet spots with a muck or bog soil. Reaction is strongly acid with a pH of 5.0. The Kamae site was a former cane field that was abandoned because of poor yields. It is typical of much of the land available for tree planting and was therefore included in the provenance tests. The site was prepared for planting with a cutaway harrow.

PROCEDURES

Seedlings, grown in plastic containers at the BioEnergy Development Corporation nursery, were planted at a spacing of 2 by 2 m (6.5 by 6.5 ft) in holes made with a dibble the same size as the root mass of the plants. The seedlings were given one 26 g application of 10-30-10 fertilizer at planting.

The first two experiments were planted in September 1979 at Akaka and Upper Ninole. These experiments were complete randomized blocks with 12 replications of 4-tree row plots of each provenance. The third experiment was planted at Lower Ninole in April 1981; the fourth, at Kamae in June 1981. These two experiments were also randomized blocks, but the number of plots per provenance varied from 4 to 24, depending on the availability of seedlings.

Survival counts were made at 3 months and height measurements at 6 and 12 months, then annually. Diameter measurements began as soon as trees reached breast height of 1.3 m (4.5 ft). For most trees, this was at the 1-year measurement.

In February 1982, a severe windstorm caused extensive blowdown in the Upper Ninole experiment, which was then 27 months old. *E. grandis,* because of its greater height, was more severely damaged than *E. saligna.* The 123 *E. grandis* and 101 *E. saligna* blown down or broken off were cut off at stump height and observed for coppicing ability. Cross-sections were taken at breast height for measurement of specific gravity which was done by the immersion method.

Another windstorm in January 1985 broke off, uprooted, or bent to the ground 60 percent of the trees at both Upper and Lower Ninole. Immediately after the storm, the diameter at the point that was or had been at breast height was measured on all the trees. The tree diameters at Akaka and Kamae were also measured to compare their basal area with that of the experiments that had been destroyed. Basal area as reported in this paper is the mean basal area of each 4-tree (16 m^2) plot expressed on a per hectare basis.

One month after the windstorm, the two stands at Ninole were clearcut so that coppicing ability could be studied. In Upper Ninole, a 25 mm thick cross-section was taken from the 3 to 7 m (10 to 24 ft) height of one tree in each 4-tree plot until 10 samples of each provenance had been collected. Specific gravity samples prepared from these cross-sections were approximately 25 mm square, with a length from the pith to the cambium. Such samples over-represent the low-density juvenile wood in a cross-section, but make the proportion of wood types in each sample more uniform for comparison purposes.

Volume estimates were based on an equation which assumed that the tree was a cylinder of the breast-height diameter outside the bark from 0 to 1.3 m (0 to 4.5 ft) and a cone with the same base diameter as the cylinder from 1.3 m (4.5 ft) to the total height. Therefore, the volume figures slightly underestimate true stem volume.

Analyses were based on the general linear model procedures of SAS version 82.4 (SAS Institute 1982). Plot means were compared by the Bonferroni (Dunn) t-test.

RESULTS

Most comparisons are based on measurements of November 1983 *(tables 2, 3, 4).* Because January 1985 storm damage prevented height measurements in two of the stands, only basal area derived from diameter measurements is presented to compare the growth of the four stands at the most recent measurement *(table 5).*

Table 2—*Ranked mean diameter of provenances of* Eucalyptus grandis *and* E. saligna *at four sites, island of Hawaii*

Akaka (4.5 yrs)				Upper Ninole (4.5 yrs)				Kamae (2.5 yrs)				Lower Ninole (2.5 yrs)			
Seed lot	Species (E.)	Diam.	Group.[1]	Seed lot	Species (E.)	Diam.	Group.[1]	Seed lot	Species (E.)	Diam.	Group.[1]	Seed lot	Species (E.)	Diam.	Group.[1]
		cm				*cm*				*cm*				*cm*	
7810	grandis	12.1	a	12409	grandis	15.4	a	7810	grandis	8.7	a	10774	grandis	9.5	a
10774	grandis	9.9	ab	12423	grandis	14.9	ab	7823	grandis	8.0	ab	7823	grandis	9.1	ab
12409	grandis	9.8	abc	11035	grandis	14.2	abc	10774	grandis	8.0	abc	12422	grandis	8.6	abc
11756	saligna	9.4	abcd	12422	grandis	13.4	abcd	12409	grandis	7.5	abcd	12409	grandis	8.1	abcd
7823	grandis	9.0	abcd	12381	grandis	13.0	abcd	12422	grandis	6.9	abcd	7810	grandis	8.0	abcd
12461	grandis	8.6	abcde	7810	grandis	12.7	abcd	11025	saligna	6.9	abcd	12423	grandis	7.9	abcd
11243	grandis	8.4	abcde	10774	grandis	12.4	abcd	11035	grandis	6.6	abcde	12381	grandis	7.9	abcde
11025	saligna	8.2	abcde	11243	grandis	11.9	abcd	12145	saligna	6.4	abcde	11025	saligna	7.9	abcde
12064	saligna	7.9	abcde	12145	saligna	11.9	abcd	12381	grandis	6.0	abcde	11035	grandis	7.5	abcde
12423	grandis	7.8	abcde	11605	saligna	11.7	abcd	12064	saligna	6.0	abcde	11243	grandis	7.4	abcde
12381	grandis	7.6	abcde	11756	saligna	11.6	abcd	12423	grandis	5.9	abcde	12143	saligna	7.0	abcde
12422	grandis	7.4	abcde	7823	grandis	11.5	abcd	11894	saligna	5.8	abcde	7808	saligna	6.9	abcde
11605	saligna	7.2	bcde	12461	grandis	11.5	abcd	7786	saligna	5.2	bcde	11894	saligna	6.7	bcde
7786	saligna	7.2	bcde	7786	saligna	10.9	bcd	7808	saligna	5.1	bcde	11605	saligna	6.4	cde
12145	saligna	7.0	bcde	11025	saligna	10.6	bcd	11243	grandis	4.8	cde	11756	saligna	6.2	cde
12143	grandis	6.9	bcde	11894	saligna	10.5	bcd	12143	grandis	4.7	de	7786	saligna	6.2	cde
7808	saligna	6.9	bcde	12064	saligna	10.5	bcd	11605	saligna	4.7	de	12064	saligna	6.1	cde
11894	saligna	6.8	bcde	12143	grandis	10.3	bcd	10225	saligna	4.6	de	12145	saligna	5.8	de
305	saligna	6.8	bcde	7808	saligna	9.5	cd	10733	saligna	3.6	e	10225	saligna	5.7	de
11035	grandis	6.1	cde	10225	saligna	9.3	d					10733	saligna	5.3	e
10225	saligna	6.1	cde	10733	saligna	9.2	d								
10733	saligna	5.9	de	305	saligna	9.1	d								
Mean grandis		8.4				12.8				6.6				8.1	
Mean saligna		7.1				10.5				5.3				6.3	
Min. signif. dif.		3.77				3.77				3.52				2.64	
Harmonic mean cell size		11.95				10.40				7.26				13.25	

[1]Means followed by the same letter are not significantly different at the 5 percent level.

Table 3—*Ranked mean height of provenances of* Eucalyptus grandis *and* E. saligna *at four sites*

Akaka (4.5 yrs)				Upper Ninole (4.5 yrs)				Kamae (2.5 yrs)				Lower Ninole (2.5 yrs)			
Seed lot	Species (*E.*)	Height	Group.[1]	Seed lot	Species (*E.*)	Height	Group.[1]	Seed lot	Species (*E.*)	Height	Group.[1]	Seed lot	Species (*E.*)	Height	Group.[1]
		m				*m*				*m*				*m*	
7810	grandis	12.1	a	12423	grandis	17.5	a	7810	grandis	11.0	a	10774	grandis	11.3	a
10774	grandis	11.4	ab	12409	grandis	17.3	a	10774	grandis	9.7	ab	7823	grandis	10.5	ab
12409	grandis	11.1	ab	11035	grandis	16.6	ab	7823	grandis	9.6	ab	12422	grandis	10.3	abc
11756	saligna	10.5	abc	10774	grandis	15.7	abc	12409	grandis	9.2	ab	7810	grandis	10.1	abcd
7823	grandis	10.4	abc	12422	grandis	15.5	abc	12422	grandis	9.2	abc	12423	grandis	9.7	abcde
12461	grandis	9.9	abcd	12145	saligna	15.5	abc	11025	saligna	8.4	abcd	12409	grandis	9.6	abcdef
12064	saligna	9.5	abcd	12381	grandis	15.5	abc	11035	grandis	8.2	abcde	12381	grandis	9.6	abcdef
11243	grandis	9.5	abcd	11243	grandis	15.3	abc	12145	saligna	7.7	abcde	11025	saligna	9.3	abcdef
12381	grandis	9.4	abcd	7810	grandis	15.2	abc	11894	saligna	7.7	abcde	11035	grandis	9.2	abcdef
12422	grandis	9.3	abcd	7823	grandis	15.1	abc	12381	grandis	7.6	abcde	11243	grandis	9.2	abcdef
12423	grandis	9.3	abcd	11605	saligna	15.0	abc	12423	grandis	7.4	abcde	11894	saligna	9.0	abcdef
12145	saligna	8.9	abcd	12064	saligna	14.2	abc	12064	saligna	6.9	bcde	12143	grandis	8.7	bcdef
11025	saligna	8.8	abcd	11894	saligna	13.6	abc	7786	saligna	6.4	bcde	7808	saligna	8.7	bcdef
11894	saligna	8.7	abcd	12461	grandis	13.6	abc	10225	saligna	6.3	bcde	11605	saligna	8.6	bcdef
11605	saligna	8.5	bcd	7786	saligna	13.5	abc	7808	saligna	6.2	bcde	12145	saligna	8.2	bcdef
12143	grandis	8.4	bcd	11756	saligna	13.3	abc	11605	saligna	6.0	bcde	12064	saligna	8.1	bcdef
7808	saligna	8.4	bcd	11025	saligna	13.0	abc	12143	grandis	5.4	cde	7786	saligna	7.9	cdef
7786	saligna	8.1	bcd	12143	grandis	12.9	abc	11243	grandis	5.2	de	11756	saligna	7.8	def
305	saligna	8.1	bcd	7808	saligna	12.2	bc	10733	saligna	4.5	e	10225	saligna	7.4	ef
11035	grandis	7.5	cd	305	saligna	11.7	bc					10733	saligna	7.2	f
10225	saligna	7.4	cd	10225	saligna	11.5	bc								
10733	saligna	6.7	cd	10733	saligna	11.4	c								
Mean grandis		9.8				15.5				8.1				9.8	
Mean saligna		8.5				13.2				6.6				8.3	
Min. signif. dif.		3.54				4.92				4.11				2.48	
Harmonic mean cell size		11.95				10.40				7.37				13.25	

[1]Means followed by the same letter are not significantly different at the 5 percent level.

Table 4—*Ranked mean annual volume per hectare of provenances of* Eucalyptus grandis *and* E. Saligna *at four sites*

Akaka (4.5 yrs)				Upper Ninole (4.5 yrs)				Kamae (2.5 yrs)				Lower Ninole (2.5 yrs)			
Seed lot	Species (*E.*)	Vol/ha/yr[1]	Group.[2]	Seed lot	Species (*E.*)	Vol/ha/yr[1]	Group.[2]	Seed lot	Species (*E.*)	Vol/ha/yr[1]	Group.[2]	Seed lot	Species (*E.*)	Vol/ha/yr[1]	Group.[2]
		m^3				m^3				m^3				m^3	
7810	grandis	32.0	a	12409	grandis	81.7	a	7810	grandis	30.7	a	10774	grandis	37.1	a
12409	grandis	26.7	ab	12423	grandis	74.9	ab	7823	grandis	25.5	ab	7823	grandis	33.8	ab
10774	grandis	25.8	ab	11035	grandis	63.2	abc	10774	grandis	23.9	abc	12422	grandis	32.8	abc
12461	grandis	22.2	abc	12422	grandis	55.6	abcd	12409	grandis	21.1	abcd	12409	grandis	27.8	abcd
11756	saligna	21.5	abc	7810	grandis	54.5	abcd	11025	saligna	18.7	abcde	11025	saligna	27.6	abcd
7823	grandis	21.3	abc	12381	grandis	53.7	abcd	12422	grandis	18.2	abcde	7810	grandis	26.9	abcd
11243	grandis	19.8	abc	10774	grandis	49.7	abcd	11035	grandis	17.1	abcde	12381	grandis	26.9	abcd
12423	grandis	19.0	abc	12461	grandis	49.7	abcd	12381	grandis	15.2	abcde	12423	grandis	25.3	abcd
11025	saligna	18.5	abc	7823	grandis	48.6	abcd	12145	saligna	15.1	abcde	11243	grandis	23.7	abcd
12064	saligna	15.6	abc	11243	grandis	47.4	bcd	12064	saligna	14.8	abcde	11035	grandis	23.2	abcd
12381	grandis	15.6	abc	12145	saligna	47.0	bcd	11894	saligna	14.6	abcde	7808	saligna	21.1	abcd
12422	grandis	15.0	abc	11756	saligna	44.1	bcd	12423	grandis	14.1	bcde	12143	grandis	18.5	bcd
11605	saligna	13.5	bc	11605	saligna	42.4	bcd	7786	saligna	11.7	bcde	11756	saligna	18.4	bcd
7808	saligna	13.1	bc	11025	saligna	39.7	cd	11243	grandis	11.0	bcde	11894	saligna	17.6	bcd
7786	saligna	13.0	bc	12143	grandis	37.0	cd	7808	saligna	10.7	bcde	11605	saligna	17.3	bcd
12143	grandis	12.6	bc	11894	saligna	35.7	cd	11605	saligna	9.0	cde	7786	saligna	16.5	cd
305	saligna	11.9	bc	12064	saligna	34.5	cd	12143	grandis	9.0	cde	12064	saligna	14.6	d
11035	grandis	11.3	bc	7808	saligna	34.0	cd	10225	saligna	8.6	de	10225	saligna	14.2	d
10225	saligna	10.9	bc	7786	saligna	33.8	cd	10733	saligna	4.5	e	12145	saligna	13.7	d
12145	saligna	10.9	bc	10225	saligna	29.9	cd					10733	saligna	12.3	d
11894	saligna	10.4	bc	305	saligna	27.6	d								
10733	saligna	7.5	c	10733	saligna	26.9	d								
Mean grandis		20.1				56.0				18.6				27.6	
Mean saligna		13.3				36.0				12.0				17.3	
Min. signif. dif.		18.2				38.89				16.40				16.7	
Harmonic mean cell size		11.95				10.40				7.26				13.25	

[1]Assumes 2500 trees per hectare (2 m spacing).

[2]Means followed by the same letter are not significantly different at the 5 percent level.

Table 5—*Ranked basal area (BA) of provenances of* Eucalyptus grandis *and* E. saligna *at four sites, island of Hawaii*

Akaka (5.3 yrs)				Upper Ninole (5.3 yrs)				Kamae (3.5 yrs)				Lower Ninole (3.7 yrs)			
Seed lot	Species (*E.*)	BA/ha	Group.[1]	Seed lot	Species (*E.*)	BA/ha	Group.[1]	Seed lot	Species (*E.*)	BA/ha	Group.[1]	Seed lot	Species (*E.*)	BA/ha	Group.[1]
		m²				*m²*				*m²*				*m²*	
7810	grandis	20.2	a	12409	grandis	28.0	a	7810	grandis	11.8	a	10774	grandis	14.5	a
12409	grandis	17.3	ab	12423	grandis	27.5	ab	7823	grandis	10.9	ab	7823	grandis	14.1	ab
10774	grandis	15.5	abc	12381	grandis	25.6	abc	10774	grandis	10.1	abc	12422	grandis	12.5	abc
12461	grandis	14.2	abc	12422	grandis	22.2	abcd	12409	grandis	9.3	abcd	12409	grandis	11.4	abcd
12423	grandis	13.4	abcd	11035	grandis	21.9	abcd	12422	grandis	7.4	bcd	12423	grandis	11.1	abcde
7823	grandis	13.3	abcd	7810	grandis	20.6	abcd	11025	saligna	6.8	bcd	11025	saligna	10.3	abcdef
11243	grandis	13.2	abcd	12145	saligna	20.2	abcd	11035	grandis	6.4	bcd	7810	grandis	10.2	abcdef
11756	saligna	12.8	abcd	11243	grandis	20.1	abcd	12423	grandis	6.2	bcd	11035	grandis	10.2	abcdef
12381	grandis	12.4	abcd	10774	grandis	20.0	abcd	12145	saligna	6.1	bcd	12381	grandis	9.8	abcdef
12064	saligna	10.1	abcd	11605	saligna	19.6	abcd	12381	grandis	5.8	bcd	11243	grandis	9.5	abcdef
12422	grandis	9.9	abcd	7823	grandis	19.3	abcd	12064	saligna	5.2	cd	12143	grandis	9.1	bcdef
11025	saligna	9.8	abcd	11025	saligna	17.6	abcd	11894	saligna	5.2	cd	7808	saligna	8.5	bcdef
7808	saligna	8.8	bcd	11756	saligna	16.7	abcd	11243	grandis	4.4	def	11756	saligna	7.4	cdef
11035	grandis	7.7	bcd	12461	grandis	16.3	abcd	10225	saligna	4.0	ef	11894	saligna	6.7	def
12145	saligna	7.6	bcd	10225	saligna	14.3	bcd	7808	saligna	3.8	ef	12064	saligna	6.6	def
0305	saligna	7.6	bcd	12143	grandis	14.2	cd	7786	saligna	3.8	ef	7786	saligna	6.6	def
12143	saligna	7.6	bcd	7786	saligna	14.1	cd	12143	grandis	3.5	ef	11605	saligna	6.3	def
11605	saligna	7.3	bcd	7808	saligna	13.7	cd	11605	saligna	3.5	ef	12145	saligna	5.7	ef
11894	saligna	7.1	bcd	12064	saligna	13.5	cd	10733	saligna	1.8	f	10225	saligna	4.8	f
7786	saligna	6.9	bcd	11894	saligna	12.1	d					10733	saligna	4.7	f
10225	saligna	5.8	cd	10733	saligna	11.4	d								
10733	saligna	2.9	d	0305	saligna	9.7	d								
Mean grandis		13.2				21.4				7.6				11.2	
Mean saligna		7.9				14.8				4.5				6.8	
Min. signif. dif.		11.13				13.19				5.10				6.60	
Harmonic mean cell size		11.98				10.54				8.70				12.98	

[1]Means followed by the same letter are not significantly different at the 5 percent level.

Species Comparison

In all four experiments *(tables 2-5),* the mean increments of diameter, height, and volume, and mean basal area of all *E. grandis* provenances combined were larger than those of *E. saligna*. In all four experiments (each with 10 or 11 treatments of each species), at least one *E. saligna* appears in the upper half of the rankings, indicating without further analysis that we cannot be confident that *E. grandis* will rank higher than *E. saligna* 95 percent of the time. The groupings show that few of the provenances within a species differed significantly from one another either. Despite this lack of significant difference, it is quite obvious that most *E. grandis* provenances grew faster than most *E. saligna.* Of 22 seed lots at Akaka and Upper Ninole, only three *E. saligna* at Akaka and one at Upper Ninole were among the top 11 in volume increment *(table 4).* Similarly, in the other two experiments, one *E. saligna* and three *E. saligna* were among the top 10 provenances in volume increment.

Basal area, obtained from diameter measurements made 1 year later, indicated relationships between the two species similar to those found for the earlier data *(table 5).* In each experiment, *E. grandis* had an overall mean basal area larger than that of *E. saligna*—as with the other data, not significantly larger at the 5 percent level. Most *E. grandis* provenances produced one-third more to twice as much basal area as most *E. saligna* provenances at each of the four sites. Basal area is probably a better measure of overall performance of the provenances than means of height and diameter because it is affected by the absence of trees that do not survive. The other data are the means only of the survivors.

Provenance Comparison

In general, provenances reacted similarly at Akaka and Kamae, which are about 2 km apart. Provenance performance was also rather similar between Upper and Lower Ninole, but growth of provenances at the Akaka and Kamae sites was somewhat dissimilar to that at the two Ninole sites. Comparing provenance performance among all four experiments, provenance 7810 had the largest sample mean at Akaka and Kamae, but was only from fourth to ninth highest in diameter, height, and volume growth at Upper and Lower Ninole *(tables 2-4).* Provenance 12409 had the largest sample mean at Upper Ninole; and provenance 10774 had the largest at Lower Ninole. The slowest growing provenance at all four sites was *E. saligna* seed lot 10733, collected near Raymond Terrace, New South Wales. Provenance 12143 was consistently the lowest ranking of the *E. grandis* provenances at the four sites.

Generally, provenances 7810, 12409, 10774, and 7823 did well at all four sites. Although *E. saligna* provenance 11025 grew quite well at Kamae and Lower Ninole and fairly well at Akaka, it was quite poor at Upper Ninole. Interestingly, Hawaii-grown *E. saligna* seed lot number 305 performed poorly in the two tests where it was used. It did not exhibit the improvement some might expect from a "land race." However, as amply demonstrated by the variation among all the provenances, the value of the "land race" concept cannot be judged from the performance of a single seed lot.

Basal area—obtained one year later than the measurements from which volume was derived—provided slightly more distinct separations of provenance means than other measures *(table 5)*. As with volume growth, provenances 7810, 12409, 10774, and 7823 did well at all four sites. Similarly, *E. saligna* provenance 10733 ranked lowest or nearly lowest.

Correlation with Latitude and Elevation

Provenance 7810, the southernmost of the *E. grandis* provenances, came from a low elevation of 120 m (390 ft). It performed best at the relatively cool Akaka and Kamae sites. Provenance 12409, from 940 m (3080 ft) near the north end of the range of *E. grandis* at Ravenshoe, Queensland, did best at the warm Upper Ninole site, but provenance 10774, from the central part of the species range and at a middle elevation, did best at the equally warm and only slightly lower elevation Lower Ninole site. Provenance 11025, northernmost of the *E. saligna* provenances, grew best for that species at the two Ninole sites. This seemed consistent with the more nearly tropical climate of the seed source location.

A multiple regression analysis of volume per tree on latitude adjusted for elevation gave an r^2 of only 0.38. The adjustment of latitude consisted of adding one degree for each 60 m (200 ft) elevation above sea level.

Correlation of Measurements

In 1982, a similar analysis of the four provenance tests was reported (Crabb et al. 1982). The measurements it reported were for 3-year growth of the two older experiments and 12 and 14 months for the two younger experiments. A comparison of these data with the current data indicated that the best and worst performers were already apparent at 1 year and were fairly definite by 3 years. This suggests that shorter-term results are reliable for experiments of this type. However, appreciable change occurred in the ranking order of seed lots nearer the mean.

Table 6—*Ranked mean specific gravity of wood at 3 to 5 meters height and estimated mean stem dry weight annual increment for provenances of* Eucalyptus grandis *and* E. saligna *at Upper Ninole at 5.3 years of age, island of Hawaii*

Seed lot	Species (*Eucalyptus*)	Specific gravity	Grouping[1]	Stem[2]
				tonnes/ha/yr
11894	saligna	0.430	a	15.4
12064	saligna	.427	ab	14.7
10225	saligna	.425	ab	12.7
11605	saligna	.414	abc	17.5
12145	saligna	.414	abc	19.5
305	saligna	.413	abcd	11.4
7808	saligna	.410	abcd	13.9
10733	saligna	.404	abcd	10.9
11025	saligna	.404	bcde	16.0
7786	saligna	.402	bcde	13.6
11756	saligna	.397	bcdef	17.5
12143	grandis	.393	cdefg	14.5
10774	grandis	.387	defg	19.2
12381	grandis	.382	defg	20.5
12422	grandis	.379	efg	21.0
11243	grandis	.378	efg	17.9
12423	grandis	.372	fg	27.9
12409	grandis	.371	fgh	30.3
7810	grandis	.352	hi	19.2
7823	grandis	.349	i	17.0
12461	grandis	.341	i	16.9
11035	grandis	.337	i	21.3
Mean saligna		.413		14.9
Mean grandis		.367		20.5
Mean significant dif.		.019		
Harmonic mean cell size		10.00		

[1]Means followed by the same letter not significantly different at the 5 percent level.
[2]Vol/ha/yr *(table 4)* × specific gravity (kg/m^3) × 1000.

Specific Gravity of the Wood

At age 5 years, significant differences in specific gravity of wood at the 3 to 7 m (10 to 24 ft) height had developed in the provenances at Upper Ninole *(table 6)*. The combined *E. saligna* provenances had a mean specific gravity significantly higher than *E. grandis*, and three *E. saligna* provenances each had denser wood than even the densest of the *E. grandis* provenances.

By combining the mean annual volume increment *(table 4)* with the specific gravity expressed in kg/m^3, a weight yield for the provenances at Upper Ninole was estimated *(table 6)*. The estimates indicate that higher weight yield would be obtained from *E. grandis* on the average despite the much higher density of *E. saligna* wood. *E. grandis* provenances 12409, 12423, 11035, and 12422 ranked highest in weight yield due primarily to fast growth at the Upper Ninole site. Provenance 11035, with the lowest density wood of any provenance, still ranked fourth in weight yield.

Although the specific gravity of the wood at breast height was fairly wide ranging among trees damaged by wind at age 2 years, none of the differences was significant *(table 7)*. As would be expected, *E. saligna* was slightly denser than *E. grandis* even at only 2 years of age. The relationship between specific gravity at 2 and 5 years was weak *(tables 6, 7)*.

Coppicing Ability of Stumps

Coppicing ability was rated 6 months after the trees damaged in the 1982 storm had been felled and 3 months after the stand was clear felled following the 1985 storm. Coppicing was considered successful if one or more sprouts grew from the stump of a felled tree. With one exception, all of the stumps that sprouted after both storms did so profusely *(table 7)*. Quite likely, coppicing ability was negatively influenced by the heavy shade of the trees still standing following the first storm. No shading was present after the stand was clear felled, but the percentage of sprouted stumps was still rather poor *(table 7)*. Note that there is little if any correlation between the percentage of coppiced stumps at 2 years and at 5.3 years. Some provenances that had a low percentage at 2 years had a high percentage 3 years later. Because of the apparent large variation from tree to tree regardless of seed source, it is probable that coppicing ability must be improved by vegetative propagation of selected individuals rather than by seed source selection.

Table 7—*Specific gravity of wood at age 2 years and sprouting of stumps at ages 2 and 5.3 years of trees cut after windthrows at Upper Ninole, island of Hawaii*

Seed lot	2 years			5.3 years	
	Total stumps	Specific gravity	Coppiced stumps	Total stumps	Coppiced stumps
			pct		*pct*
			Eucalyptus grandis		
7810	16	0.359	25	45	52
7823	15	.360	40	48	58
11243	10	.370	40	50	52
10744	12	.357	50	45	67
12143	6	.390	83	50	52
11035	10	.328	30	48	69
12423	7	.363	29	45	84
12422	11	.364	55	45	64
12381	8	.354	25	45	76
12409	13	.346	31	48	73
12461	15	.349	73	40	70
Mean		0.358	44		65
			Eucalyptus saligna		
7786	4	0.350	25	36	81
10225	7	.377	71	35	66
10733	1	.400	100	35	63
7808	18	.406	50	36	58
11605	4	.390	75	46	65
11894	12	.410	67	45	69
11756	11	.380	36	40	65
12145	7	.380	57	37	81
12064	11	.390	18	45	58
11025	12	.367	67	44	73
0305	14	.392	43	4	45
Mean		0.386	55		66

DISCUSSION AND CONCLUSIONS

Despite the lack of statistically significant difference between so many of the means, the consistent results among the four experiments indicates that selection of the best performing provenances should pay off. Consistency was higher among the poorest performers than among the best, suggesting that they can be eliminated from consideration with confidence.

The mean annual volume increment figures probably exaggerate differences between provenances *(table 4)*. Overtopping and shading out of slower growing provenances by those with faster growth is the primary cause. This would be less obvious if blocks rather than row plots had been used. Also, the multiplier of 2500 trees per hectare exaggerates what would result naturally from windthrow and death from suppression. The volume growth reported for several provenances appears higher than could be expected under normal management. These "plot" data are useful for comparison, but may overstate the growth and yield obtained in actual management practice. The basal area data, however, fall well within the range of values found in South Africa (Food and Agriculture Organization 1979, Darrow 1983).

The relationship between latitude or elevation of a provenance and its growth in Hawaii was poor. In general, it can be assumed that *E. grandis* did better than *E. saligna* because its range in Australia more closely approximates the latitude of Hawaii. But this does not explain why both seed lot 7810 from the southernmost part of the range and seed lot 12409 from some 900 miles further north did well at all sites. The relationship of growth in Hawaii to provenance latitude is a little better for *E. saligna*; the northernmost seed lot 11025 grew as well as the better *E. grandis* on three sites, and the southern seed lots 10733, 10225, and 7786 did very poorly.

It appears that the individual ecotypes represented by the more successful provenances must be used in Hawaii. Therefore, for sites generally similar to Akaka and Kamae, the following provenances of *E. grandis* should be used: 7810 from Bulahdelah, New South Wales; 12409 from Ravenshoe, Queensland; 10774 from Gympie, Queensland; and 7823 from Coff's Harbor, New South Wales. For sites similar to

Ninole Valley in Kau, *E. grandis* provenances 12409 and 10774 should be the best choices. These better growing provenances of *E. grandis* should be used at these sites and *E. saligna* should be discontinued.

The remaining three stands will be clear felled at the conclusion of this study to determine total biomass production, wood specific gravity, and coppicing ability. Until then, it is recommended that seed collections be made in Australia of the best growing *E. grandis* trees at those sites where the best provenances *(tables 1, 4)* were collected. Seedlings grown from these collections should be planted on sites in Hawaii that are comparable to those in this study.

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Australian provenances of *Eucalyptus grandis* and *E. saligna* were compared at four locations on the island of Hawaii to seek seed sources better than those in current use which were introduced earlier from unrecorded locations in Australia. A broad range of latitude and elevation was represented among the provenances. At all four locations, most *E. grandis* provenances outgrew most *E. saligna.* Considerable consistency was demonstrated among the good and poor provenances at each site. Although most differences between provenances were not statistically significant at the 5 percent level, the consistently good performance of several *E. grandis* provenances led to the recommendation that these seed sources be collected in Australia for future planting on similar sites on the island.

Retrieval Terms: Eucalyptus grandis, Eucalyptus saligna, genetics, provenance tests, Hawaii