PERFORMANCE OF *EUCALYPTUS GLOBULUS*, *E. MAIDENII*, *E. NITENS*, AND OTHER EUCALYPTS IN NORTHLAND AND HAWKE'S BAY AT AGES 7 AND 11 YEARS

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ABSTRACT

Species and provenance trials of eucalypts, planted independently, near Kaikohe in Northland and at Clive in coastal Hawke's Bay were assessed at ages 7 and 11 years, respectively. At Kaikohe, 11 provenances of *Eucalyptus nitens* (Deane et Maiden) Maiden, six of *E. saligna* Smith, three of *E. grandis* Hill ex Maiden, two each of *E. globulus* Labill. and *E. maidenii* Labill., and one of *E. robusta* Smith were included; at Clive, 21 species were involved, including *E. globulus*, *E. maidenii*, and *E. bicostata* Labill., and provenances of *E. nitens* from central Victoria (Vic) and southern New South Wales (NSW). At Kaikohe three replications of 49-tree square plots were planted of each seedlot at 2.0 × 1.9 m spacing, and at Clive the trial consisted of eight replications of 18-tree plots at 2 × 1 m spacing.

At a third site at Patoka, north-west of Napier, transect comparisons were made of *E. nitens* (Vic), *E. maidenii,* and *E. bicostata* at age 11 years.

At Kaikohe (age 7 years), the best growth was achieved by *E. nitens* (Vic) and *E. nitens* (NSW) (equal; dbh 200 mm), followed by *E. globulus* and *E. maidenii* (equal; dbh 172 mm). However, the *E. nitens* (Vic) provenances showed a widespread, unidentified disorder in the form of progressive loss of the lower crown and eventual death of the tree. Their "survival" (after a 50% early thinning) averaged half that of the NSW provenances which had healthy crowns. *Eucalyptus globulus* showed a similar problem to *E. nitens* (Vic), but *E. maidenii* retained good crowns and high survival.

At Clive (age 11 years), a periodic high water table affected survival and health of some species more than others. *Eucalyptus nitens* (Vic) grew well (dbh 200 mm), though survival was poorer than that of the NSW provenance and crown health was much poorer, with the same progressive loss of lower crown and death (also windthrow) as was seen at Kaikohe. *Eucalyptus globulus* had grown a little better than both *E. nitens* provenances, but showed similar crown death to *E. nitens* (Vic). *Eucalyptus maidenii* had a higher mean dbh (219 mm) than all other species and had maintained a high survival. At Patoka, growth, form, and health of *E. nitens* (Vic) and *E. maidenii* were excellent, with *E. maidenii* a little slower-growing.

The good health and much higher wood density of *E. maidenii* than of *E. nitens* indicate its potential value for pulpwood, e.g., at Clive (from a disc study at age 10 years) weighted whole-tree basic density of *E. maidenii* was 582 kg/m^3 as against 450 kg/m^3 for *E. nitens*.

Keywords: species trials; provenance; growth; survival; form; wood density; *Eucalyptus nitens; Eucalyptus globulus; Eucalyptus maidenii.*

INTRODUCTION

There have been few species trials established in New Zealand with eucalypts since those undertaken by Wilcox and co-workers in the 1970s (Johnson & Wilcox 1989; Wilcox *et al.* 1985). Since that time, several species that were previously well regarded have fallen into disfavour, through attack by pests and diseases, or through poor environmental adaptation, or by the manifestation of poor wood properties and utilisation performance. Furthermore, the objectives of growing eucalypts have now polarised more definitely into growing short-rotation pulpwood for kraft or chemi-mechanical pulping (and possibly fuel) on the one hand, *v.* longer-rotation management for solid wood products on the other.

In this situation there is a need for more species and provenance introduction and testing, on a wide range of sites, including the planting of blocks of selected provenances of different species to provide growth modelling, silvicultural, and utilisation information, as well as demonstrations to small growers and the forest industry of the potential of "new" species.

Eucalyptus nitens has become the most widely-planted species for short-fibred pulp in New Zealand because of its wide adaptability, including frost-hardiness, and its rapid growth and good form. It is followed for this purpose by *E. fastigata* Deane et Maiden which, though slower-growing initially, is well-regarded for its consistent good health and tolerance or resistance to both fungal and insect pests. Work on provenance and progeny testing of *E. nitens*, initiated in the late 1970s, showed that the central Victorian provenances grew substantially faster, at least during the first 8 years, than those from New South Wales on the central North Island and South Island sites tested.

Subsequent development of a breeding programme and commercial planting have focused mainly on central Victorian provenances. Each regional group of provenances in this species is genetically distinct and there are some recent indications of superior health of New South Wales populations in warmer climates (T.Withers & M.O.Kimberley unpubl. data).

The subspecies* of *E. globulus* were likewise disregarded in earlier trials, with a token testing of just *E. globulus.* A single trial was planted in the Bay of Plenty at Omataroa in 1993 which included eight provenances of *E. globulus* and one each of *E. bicostata* and *E. pseudoglobulus* Labill., as well as single seedlots of *E. nitens* from central Victoria and southern New South Wales, *E. regnans* F.Mueller, and *E. fastigata* (S. Concheyro unpubl. data). A major trial involving a total of 30 provenances of all four subspecies of *E. globulus* was planted at four sites in 1999.

Two independently-planned trials of species and provenances, which included both New South Wales and central Victorian provenances of *E. nitens*, *E. globulus*, and *E. maidenii* as well as many other species, were planted near Clive in Hawke's Bay in 1987 and near Kaikohe in Northland in 1991. A further farm-woodlot planting of *E. nitens* (central Vic), *E. maidenii*, and *E. bicostata* was made at Patoka, Hawke's Bay, in 1987. These trials are the

* Note: *Eucalyptus globulus* and its close relatives *E. maidenii, E. bicostata,* and *E. pseudoglobulus* are often alternatively treated as subspecies of a single species, *E. globulus* (Kirkpatrick 1975). They will for convenience be referred to as separate species here.

oldest, providing the only comparisons in New Zealand of *E. globulus* and related species with *E. nitens* (outside the 1993 trial)*, and results of assessment at ages 11 and 7 years respectively are reported here. Although there were no seedlots in common, the following species and provenance groups were common to Kaikohe and Clive: *E. globulus*, *E. maidenii*, *E. botryoides* Smith, *E. saligna*, *E. nitens* (central Vic), and *E. nitens* (southern NSW). *Eucalyptus nitens* (central Vic), *E. maidenii*, and *E. bicostata* were common to Clive and Patoka.

SITES

The trials were located at three sites in the North Island (Table 1): Knudsen Road, near Kaikohe (60 km north-west of Whangarei); Pakowai, near Clive (10 km south of Napier); and Patoka (30 km north-west of Napier).

The Knudsen Road site was on a typically variable Northland clay, with rolling topography and a capping of volcanic ash in part of the trial. The Pakowai (near Clive) site was flat and located between the stop-banks of the Tutaekuri and Ngaruroro rivers; it had a periodically high water table, restricting rooting depth. Patoka had good air drainage into the deeply-incised valleys on either side, and a deep volcanic ash soil. The altitudes were respectively 250 m, 5 m, and 350 m.

TABLE 1–Description of trial sites

	Kaikohe	Clive	Patoka
Latitude	35° 25′	39° 36′	39° 21′
Longitude	173° 50′	176° 55′	176°38′
Altitude	250 m	5 m	350 m
Annual rainfall	1800 mm	800 mm	1300 mm
Aspect	Rolling	Flat	15° slope to North
Soil	Part northern yellow-brown earths (clay), part red-brown loam (volcanic)	Loess over silt and gravel	Volcanic ash

MATERIAL AND TRIAL DESIGNS

Knudsen Road, Kaikohe

A randomised complete block design was used for the trial which was planted in 1991 at an initial spacing of 2.0 × 1.9 m (2632 stems/ha), with three replications of 49-tree square plots. There were 27 seedlots in 78 plots (a total of three missing plots), representing 11 provenances of *E. nitens*, six provenances of *E. saligna*, three provenances of *E. grandis*, two provenances of *E. botryoides*, one of *E. robusta*, and two each of *E. globulus* and *E. maidenii* (Table 2). All plots were thinned to half stocking at age 5 years and, subsequently, dead trees were progressively felled by the owner. An assessment of height and diameter before thinning was made at age 4 and sample plot data were recorded (Errol Hay, pers. comm.).

* A further trial with *E. maidenii* and *E. globulus*, planted in 1988, has recently been found in Northland and has been assessed since this paper was submitted.

TABLE 2–Kaikohe: Seedlot information

Code	Species	Provenance	State of origin	Seedlot	No. of parents
NN41	*E. nitens*	Mt Toorongo Plateau	Vic	CSIRO 14011	52
NN42	*E. nitens*	7 km north-north-west of Rubicon	Vic	CSIRO 16868	20
NN43	*E. nitens*	MacAlister	Vic	CSIRO 17758	25
NN44	*E. denticulata*	Errinundra Plateau	Vic	CSIRO 16310	10
NN45	*E. nitens*	Brown Mountain	S. NSW	CSIRO 14012	11
NN46	*E. nitens*	Tallaganda State Forest	S. NSW	CSIRO 16619	45
NN47	*E. nitens*	Badja State Forest	S. NSW	CSIRO 14438	7
NN48	*E. nitens*	Barrington Tops	N. NSW	CSIRO 16902	8
NN49	*E. nitens*	Rotoaira (New Zealand)	Vic	NZ 89/196	?
NN4A	*E. nitens*	Mount Erica	Vic	ortet 888.854	1
NN4B	*E. nitens*	Connors Plain	Vic	ortet 888.874	1
SS41	*E. saligna*	Tairua Seed Orchard	NZ	NZ 89/003	9
SS42	*E. saligna*	North Durras, Kiola State Forest	NSW	CSIRO 11675	3
SS43	*E. saligna*	Armidale	NSW	CSIRO 13335	10
SS44	*E. saligna*	East of Guyra	NSW	CSIRO 13336	11
SS45	*E. saligna*	Mount Scanzi, Kangaroo Valley	NSW	CSIRO 12978	?
SS46	*E. saligna*	20 km north of Helido	Qld	CSIRO 16942	10
GR41	*E. grandis*	Kenilworth State Forest	Qld	CSIRO 14436	23
GR42	*E. grandis*	30 km north of Coffs Harbour	NSW	CSIRO 15236	25
GR43	*E. grandis*	West of Coffs Harbour	NSW	CSIRO 16839	20
BB41	*E. botryoides*	Bodalla State Forest	NSW	CSIRO 15267	10
BB42	*E. botryoides*	Cann River	Vic	CSIRO 12979	?
RR41	*E. robusta*	South-east of Nowra	NSW	CSIRO 15931	5
GG41	*E. globulus*	South of Huonville	Tas	CSIRO 16580	57
GG42	*E. globulus*	Jeeralang North	Vic	CSIRO 16633	27
GM41	*E. maidenii*	Black range via Eden	NSW	CSIRO 17742	37
GM42	*E. maidenii*	Bolaro Mountain	NSW	CSIRO 15917	7

This trial contained the most complete collection of provenances of *E. nitens* of all trials in New Zealand. Central Victorian provenances from Mt Toorongo, Rubicon, MacAlister, Mount Erica, and Connor's Plain (and mixed Victorian provenances grown from seed collected in a progeny test at Rotoaira, NZ) could be compared with southern NSW provenances from Brown Mountain, Tallaganda, and Badja, and with the extreme northernmost population from Barrington Tops, as well as the provenance from the Errinundra plateau, now known as *E. denticulata* Cook et Ladiges. For other species, *E. saligna* included four NSW provenances and one from Queensland, *E. grandis* included three NSW provenances, *E. globulus* had two contrasting provenances from southern Victoria and southern Tasmania, with two provenances of *E. maidenii* from south-eastern NSW.

Pakowai, Clive

The trial was planted in 1987 to test a range of coppicing eucalypt species for fuelwood production on a very short rotation (3–4 years). Owing to the failure of the fuelwood venture, felling did not take place, nor was any thinning done.

The trial was planted at 2 × 1 m spacing (5000 stems/ha) in a randomised complete block design with eight replications of 18-tree plots (three rows at 2 m spacing × six trees per row at 1 m). Twenty-one different species were involved, mostly with only one seedlot and often from very few parents; they included *E. globulus*, *E. maidenii*, and *E. bicostata*, and two provenances of *E. nitens* (from southern NSW and central Vic) (Table 3). A single 48-tree square block of most seedlots was planted adjacent to the trial. After assessments at ages 2 and 5 years (R.McConnochie, unpubl. data), no further measurement was done until a growth and wood density assessment of part of the trial in 1996 (F.Jamieson, unpubl. data) and a biomass study of five selected trees each from *E. globulus*, *E. maidenii*, and *E. nitens* in 1998 (G.Jansen, unpubl. data). The genetic sampling of this trial was evidently quite deficient and results need cautious evaluation.

TABLE 3–Clive: Seedlot information

Species	Seedlot No.	Seedlot origin	No. of parents
E. nitens (Vic)	FRI 78/2146, 2149, 2154	Rubicon, Mt St Gwinear, MacAlister	24
E. nitens (NSW)	FRI 76/2011	Badja SF, NSW	7
E. globulus	FRI 78/2210	Bruny Is., TAS	?
E. maidenii	2/0/80/036	Pakowai Road, Gisborne	2
E. bicostata		Unknown	
E. ovata	FRI 78/2212	Smithton, TAS	1
E. botryoides	9/0/87/021	Tairua Forest, NZ	5
E. macarthurii	9/0/81/006	Cpt. 1091, Kaingaroa	4
E. saligna		Unknown	
E. camaldulensis	8/0/82/006	Horsham, VIC	?
E. tereticornis	9/0/81/090	Narooma, NSW	1
E. regnans	2/0/86/003	Atiamuri seed stand, NZ	?
E. fastigata	8/0/86/006	Bendoc, VIC	?
E. fraxinoides	9/0/82/074	Composite NSW + VIC	42
E. elata		Unknown	
E. cinerea	8/2/82/007	Boorowa, NSW	?
E. stellulata	9/0/87/200	Victoria Park, ChCh	2
E. wilcoxii		Unknown	
E. radiata	9/0/82/092	Putaruru, NZ	6
E. nicholii	FRI 79/2341	Ex CSIRO 12405, ACT	?

Patoka

This was an unreplicated outplanting of three seedlots from the Clive trial, i.e., *E. nitens* (central Vic), *E. maidenii*, and *E. bicostata*, all planted at 2 × 1 m spacing over an area of about 4 ha, mainly of *E. nitens*, with approx. 0.5-ha strips of *E. maidenii* and *E. bicostata* running through the *E. nitens*. All species were systematically thinned at age 3 years by removing three rows out of four, and the remaining rows were thinned to leave 300-400 stems /ha. The *E. nitens* stand was further thinned for pulp at age 8 years to 170 stems/ha, and the *E. maidenii* and *E. bicostata* were thinned similarly, 2 years later, at age 10 years.

The three seedlots were sampled by two 12-tree rows of *E. maidenii* and *E. bicostata*, paired in each case with two 12-tree rows of the adjoining *E. nitens*, which was thus sampled twice.

ASSESSMENT METHODS AND DATA ANALYSIS

Diameter at breast height was measured and bole straightness, malformation, and crown health were subjectively rated according to the scales shown in Table 4. A sample of trees from the more vigorous species was measured for height at Clive and 12 trees per seedlot were similarly measured at Patoka.

TABLE 4–Assessment traits

Trait	Units	Description
Height	metres	Measured by Suunto hipsometer
Diameter	millimetres	Measured by tape measure at 1.4 m above ground level
Straightness	1–9 scale	1 = very sinuous, 9 = perfectly straight
Malformation	1–9 scale	1 = multileader, 9 = no forks or ramicorns
Health	1–9 scale	1 = completely defoliated, 9 = totally healthy crown
Status of trees not measured	categoric	–1 = dead, –2 = broken stem, –3 = too small, –4 = cut down, –5 = toppled

For crown health score, crown density (as seen from the ground below and to the side) and crown length were combined into a single subjective score from 1 (almost no live foliage) to 9 (dense deep crown).

"Survival" at the Knudsen Road trial at Kaikohe was calculated as the percentage of trees alive after a 50% thinning at age 4 years. Survival at Clive was calculated as the percentage alive of those originally planted. Survival figures were analysed as decimal fractions (where 1.0 represents 100% survival). An arcsine transformation was tried, but as there was little difference between transformed and untransformed values, untransformed data were used.

Randomised complete block designs were used at both Kaikohe and Clive. The equation for the model of a randomised complete block design is as follows:

$$Y_{ij} = \mu + \tau_i + \beta_j + \beta\tau_{ij} + \varepsilon_{ij}$$

where: Y_{ij} = individual tree value of the *i*th seedlot in the *j*th replicate
μ = the overall mean
τ_i = treatment effect of the *i*th seedlot (species or provenance)
β_j = effect of the *j*th replicate
$\beta\tau_{ij}$ = replication × seedlot interaction effect or plot-environment error
ε_{ij} = tree within-plot error

For the analysis at Clive, seedlots were assumed to be fixed and all other terms random. The same model was used on the Kaikohe data, although not technically correct, but there is merit in comparing provenances of closely related species as entities. The correct model, nesting seedlots within species, was used to compare species. In this nested model, species were assumed to be fixed and all other effects were random.

Analysis of variance was carried out using PROC GLM of SAS™ software. Tukey's multiple range test was used to indicate significance of difference between species or seedlot means for all traits at the Kaikohe and Pakowai sites. Height and diameter at breast height (dbh) of *E. maidenii* and *E. bicostata* at Patoka were compared to adjacent rows of *E. nitens* in separate T-test analyses using PROC TTEST of SAS™ software because the Patoka site was not laid out as a replicated trial.

Status scores were used to compute survival for the 18-tree plots and 48-tree blocks at Clive. Trees that were cut down or too small to measure were rated as being alive, while some recently dead or toppled trees (mainly in the *E. nitens* plots) were measured, but were noted as dead for the survival figures.

F.Jamieson (unpubl. data) determined basic wood density in the Kaikohe and Clive trials at ages 5 and 9 years respectively for *E. nitens* (Vic), *E. nitens* (southern NSW), *E. maidenii*, *E. globulus*, and *E. bicostata*. He sampled 15 or more "average size" trees per species / provenance using breast-height pith-to-bark 5-mm increment cores. G.Jansen (unpubl. data) selected five trees per species / provenance from Jamieson's data to cover the range of density in each species and determined whole-tree densities by taking cross-sectional discs at 3-m intervals, determining the density of each disc, and then calculating a weighted tree mean based on disc basal areas.

RESULTS AND DISCUSSION

Results of the assessments at Clive and Patoka, age 11 years, and at Kaikohe, age 7 years, are considered separately by site. An overall analysis was considered unsuitable and invalid; there were no seedlots in common and, although some species were planted in both trials, many others were not. There were also quite specific design, environmental, and disease problems at each site that indicated a separate analysis for each would be desirable.

Knudsen Road, Kaikohe

This trial contained a relatively complete set of provenances of *E. nitens* as well as a small sample of provenances of other species (Tables 2, 5, 6).

Eucalyptus nitens of both central Victorian and southern New South Wales provenances ranked highest of all species for mean dbh (201 mm for Vic; 200 mm for NSW), followed by *E. grandis*, *E. globulus*, and *E. maidenii* nearly equal (171 and 174 mm) and then by *E. saligna*, *E. botryoides*, and *E. robusta*. Mean diameters tell only a small part of the story, however. "Survival" (the percentage of live trees of the number left after a 50% thinning at age 4) varied dramatically between species and provenances. The Victorian provenances of *E. nitens* (Toorongo, Rubicon, MacAlister, Mt Erica, Connors Plain, and Rotoaira, NZ)

TABLE 5–Kaikohe: Species means

Species	Survival (%)	Diameter (mm)	Straightness (1–9 scale)	Malformation (1–9 scale)	Health (1–9 scale)
E. nitens (northern NSW)	96 a	177 ab	8.00 a	8.33 a	6.02 a
E. nitens (southern NSW)	91 ab	200 a	6.47 cd	8.11 ab	5.64 ab
E. denticulata	85 ab	163 bc	6.61 bcd	7.58 ab	4.83 bc
E. nitens (Vic)	42 c	200 a	7.46 ab	8.27 a	3.32 de
E. grandis	87 ab	188 ab	6.35 cd	5.71 def	6.45 a
E. globulus	65 bc	171 ab	6.08 cde	6.84 bcd	3.21 e
E. maidenii	90 ab	174 ab	6.57 bcd	7.24 abc	6.52 a
E. saligna	87 ab	163 bc	6.62 bc	6.14 cde	6.14 a
E. botryoides	68 c	141 c	5.66 de	5.08 ef	4.28 cd
E. robusta	87 ab	141 c	5.15 e	4.71 f	6.28 a

Tukey's multiple range test: means without following letters in common, differ significantly

TABLE 6–Kaikohe: Seedlot means

Species	Provenance	State	Code	Number of plots	Survival (%)	Diameter (mm)	Straightness (1–9 scale)	Malformation (1–9 scale)	Health (1–9 scale)
E. nitens	Mt Toorongo Plateau	Vic	NN41	3	28 e	201 abcd	7.10 abcde	7.57 abcdef	3.86 efg
E. nitens	7 km NNW Rubicon	Vic	NN42	3	39 de	195 abcd	7.66 abc	8.41 ab	3.21 fg
E. nitens	MacAlister	Vic	NN43	3	33 e	201 abcd	6.68 abcdef	7.68 abcde	3.60 fg
E. nitens	Rotoaira NZ	Vic	NN49	3	59 abcde	192 abcde	7.73 abc	8.75 a	3.34 fg
E. nitens	Mount Erica	Vic	NN4A	2	42 cde	214 a	8.19 a	8.81 a	3.52 fg
E. nitens	Connors Plain	Vic	NN4B	3	51 bcde	204 abc	7.32 abcd	8.08 abcd	2.79 g
E. denticulata	Errinundra Plateau	Vic	NN44	3	85 ab	163 abcdef	6.61 abcdef	7.58 abcdef	4.83 bcdef
E. nitens	Brown Mountain	NSW (S)	NN45	3	87 ab	211 ab	5.74 def	8.26 abc	5.55 abcde
E. nitens	Tallaganda SF	NSW (S)	NN46	3	91 ab	185 abcdef	6.38 bcdef	7.68 abcde	4.94 bcdef
E. nitens	Badja SF	NSW (S)	NN47	3	95 a	204 ab	7.21 abcde	8.38 ab	6.38 ab
E. nitens	Barrington Tops	NSW (N)	NN48	2	96 a	177 abcdef	8.00 ab	8.33 abc	6.02 abc
E. saligna	Seed Orchard 89/3	NZ	SS41	3	85 ab	152 cdef	7.25 abcde	6.94 abcdefgh	6.15 abc
E. saligna	North Durras, Kiola SF	NSW	SS42	3	77 abcd	165 abcdef	6.10 cdef	5.66 efgh	5.66 abcde
E. saligna	Armidale	NSW	SS43	3	95 a	167 abcdef	6.14 cdef	5.59 efgh	6.39 ab
E. saligna	East of Guyra	NSW	SS44	2	86 ab	174 abcdef	7.07 abcde	6.30 bcdefgh	6.53 ab
E. saligna	Mt Scanzi, Kangaroo Vly	NSW	SS45	3	91 ab	149 def	6.68 abcdef	5.96 cdefgh	5.85 abcd
E. saligna	20 km north of Helido	Qld	SS46	3	89 ab	175 abcdef	6.61 abcdef	6.42 abcdefgh	6.31 ab
E. grandis	Kenilworth SF	Qld	GR41	2	90 ab	211 ab	6.60 abcdef	5.82 defgh	7.00 a
E. grandis	30 km north of Coffs Harbour	NSW	GR42	3	81 abc	185 abcdef	5.85 def	5.20 fgh	6.30 abc
E. grandis	West of Coffs Harbour	NSW	GR43	3	89 ab	177 abcdef	6.63 abcdef	6.09 bcdefgh	6.21 ab
E. botryoides	Bodalla SF	NSW	BB41	3	68 abcde	143 ef	5.61 ef	5.02 gh	4.45 cdefg
E. botryoides	Cann River	Vic	BB42	3	68 abcde	139 f	5.71 def	5.14 gh	4.12 defg
E. robusta	South-east of Nowra	NSW	RR41	3	87 ab	141 ef	5.15 f	4.71 h	6.28 abc
E. globulus	South of Huonville	Tas	GG41	3	75 abcd	178 abcdef	6.13 cdef	7.02 abcdefgh	3.13 fg
E. globulus	Jeeralang North	Vic	GG42	3	56 abcde	162 bcdef	6.02 cdef	6.60 abcdefgh	3.33 fg
E. maidenii	Black Range via Eden	NSW	GM41	3	89 ab	176 abcdef	6.43 bcdef	7.27 abcdefg	6.49 ab
E. maidenii	Bolaro Mt	NSW	GM42	3	91 ab	172 abcdef	6.71 abcdef	7.21 abcdefg	6.54 ab

Tukey's multiple range test: means without following letters in common, differ significantly

(Table 6) had "survivals" averaging 43%, in comparison with the NSW provenances, including Barrington Tops (northern NSW) which averaged 94%. Errinundra (*E. denticulata*) survived well (88%), in spite of slower growth than the others.

The poor survival of the Victorian plots was evidenced by the presence of numerous dead trees, as well as stumps where dead trees had been removed. The crowns of many of the surviving trees were dying progressively from the bottom and many survivors had only a few live branches at the top of the tree. The deaths seemed to have occurred from a focus within the plot, often leaving a few trees around the edge. Apparently-dead trees would sometimes leaf out from adventitious buds on the bole or lower branches, but eventual death seemed inevitable. This situation was in sharp contrast to that in the plots of NSW origin where mortality was low (survival averaging 94%) and where crowns were generally healthy and deep, though not particularly dense.

Health scores reflected the same trend as survival; Victorian provenances of *E. nitens* averaged 3.32 *v.* 5.64 for the southern NSW provenances. It was clear that at the time of assessment the NSW provenances, particularly those from southern NSW, had much better crown health and survival than Victorian material, as well as a mean dbh that was similar to the Victorian provenances.

The crown health scores of *E. globulus* of both Tasmanian and Victorian provenances were poor and in sharp contrast to those of *E. maidenii* (3.23 *v.* 6.52). The same "disease" symptoms were shown by *E. globulus* as by the central Victorian provenances of *E. nitens*, with crowns being rapidly eroded from below. Deaths had not occurred to the same extent as in *E. nitens* (Vic), but survival averaged only 67% in contrast to 92% for *E. maidenii.* Height growth of *E. globulus*, not measured at this site, had been particularly rapid before the disease took effect. There were some adventitious shoots from the stem and lower branches in the trees with smaller crowns, but leaders were often dead and prospects for continued growth looked poor.

Sample plots had been established in the inner 25 trees of the 49-tree plots in *E. nitens, E. globulus*, and *E. maidenii* seedlots at age 4 years before thinning. Results from measurements at that age, averaged over plots and seedlots of each species that had satisfactory survival and growth, are given in Table 7 (E.Hay, unpubl. data). There was no evidence from these data of the subsequent deterioration in health, growth rate, and survival that was apparent by age 7 years; the southern NSW provenances were somewhat slower growing than *E. globulus*, and *E. maidenii* was slower growing than *E. globulus* at this age. It is clear that relative performance of the different species and seedlots was still changing with increasing age.

Differences between provenances and species were significant for both bole straightness and malformation but showed no particular pattern. Differences between provenances of

TABLE 7–Kaikohe: Age 4 sample plot results

	Stocking (stems/ha)	dbh (cm)	Height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	MAI (m^3/ha/year)
E. nitens (Vic)	2652	12.3	12.4	30.4	162	39.9
E. nitens (southern NSW)	2679	11.2	11.6	26.4	130	32.0
E. globulus	2576	10.8	10.9	23.4	115	28.3
E. maidenii	2796	9.4	10.8	19.6	90	22.3

E. nitens were as great as those between *E. nitens* and other species for bole straightness except that *E. botryoides* and *E. robusta* were significantly more crooked and had more malformation than all other species and provenances.

Eucalyptus grandis Hill ex Maiden had larger dbh and better crown health scores than *E. saligna*, a closely related species. The good performance of *E. grandis* was not expected, as it has a more subtropical distribution than *E. saligna*. It had, however, also performed well in an early *E. saligna* provenance trial at nearby Waitangi (unpubl. data). The growth, form, and health of *E. botryoides*, another closely related species, were inferior to those of *E. saligna*, as were those of *E. robusta*.

Basic wood density is of high economic importance in evaluating pulpwood species for cultivation on short rotations, and high densities are desirable for kraft pulping. There were large differences between species in this characteristic (Table 8) which are likely to be as important as the differences in growth rates, or more so. Densities averaged (at age 5 years) 399, 417, 431, and 518 kg/m^3 for *E. nitens* (Vic), *E. nitens* (NSW), *E. globulus*, and *E. maidenii* at this site. Density of *E. globulus* was only 14 kg/m^3 higher than *E. nitens* (21 kg/m^3 at Clive) and was expected to be much higher (M.D.Wilcox, pers. comm.). Outerwood densities at breast height at age 8 years for *E. nitens* (NSW), *E. globulus*, and *E. maidenii* from a 30-tree sample were 412, 438, and 535 kg/m^3 (unpubl. data).

Whole-tree weighted mean densities of five trees per species, selected to sample the range, were determined by G.Jansen (unpubl. data) at age 6 years (Table 9). These averaged 431, 479, and 555 kg/m^3 for *E. nitens* (provenance unspecified), *E. globulus*, and *E. maidenii*.

To sum up, at the Knudsen Road trial, the southern NSW provenances of *E. nitens* showed the fastest growth, best health and bole straightness, and least malformation of any species in the trial. The major contrast in crown health and survival between the NSW and central Victorian provenances was remarkable and indicated important genetic differences between

TABLE 8–Basic density derived from breast-height pith to bark increment cores (from unpubl. data of F.Jamieson)

	Clive (age 9) (kg/m^3)	Kaikohe (age 5) (kg/m^3)	Patoka (age 9) (kg/m^3)
E. nitens (Vic)	409 (28)	399 (15)	436 (30)
E. nitens (NSW)	419 (27)	417 (15)	
E. globulus	440 (24)	431 (15)	
E. maidenii	543 (23)	518 (15)	500 (31)
E. bicostata	539 (25)	–	512 (29)

Number in parenthesis after mean density is number of trees sampled

TABLE 9–Basic density (whole tree weighted mean) (from unpubl. data of G.Jansen)

	Clive (age 10) (kg/m^3)		Kaikohe (age 6) (kg/m^3)	
	Range	Mean	Range	Mean
E. nitens	416–501	449	404–435	431
E. globulus	441–515	489	444–512	479
E. maidenii	559–620	582	522–610	555

the two regional populations. *Eucalyptus globulus* had encountered a disease problem similar to the Victorian *E. nitens*, and had also grown substantially more slowly in dbh than *E. nitens*. The dbh of *E. maidenii* was about the same as *E. globulus*, but its survival and crown health were good. *Eucalyptus maidenii* had an important advantage over *E. nitens* in having a much higher wood density, over 100 kg/m^3 higher on this site at age 7 years (F.Jamieson, unpubl. data; G.Jansen, unpubl. data). Its pulping characteristics have not yet been studied but with such a high density at a young age there is a prospect that it could be grown on a much shorter rotation than *E. nitens*, which kraft pulping studies have shown must be grown for 12–15 years to realise satisfactory pulping characteristics (R.P.Kibblewhite, unpubl. data).

Pakowai, Clive

Coincidentally, survival again dominated the provenance and species comparisons at Clive. Early survival and growth (R.M.McConnochie, unpubl. data) had been poor in some species due to inadequate weed control and site variability, partly because of ash bed effects (the site was previously a poplar nursery and old stools had been burnt on the site). Subsequent mortality and poor health were evidently caused by a periodic high water table, which caused some species to die immediately; others formed shallow rooting systems which apparently caused the trees to die later from windthrow and drought. Survival percentages (Table 10) were very different amongst species; *E. elata* Dehnh., *E. cinerea* F.Mueller ex Benth., *E. stellulata* Sieb. ex DC., *E. wilcoxii* Boland et Kleinig, *E. radiata* Sieb. ex DC., *E. nicholii* Maiden et Blakely, *E. regnans*, *E. fastigata*, and *E. fraxinoides*

TABLE 10–Clive: Seedlot means

Species	Survival (%)	Survival excluding runts (%)	Diameter (mm)	Height (max) (m)	Straightness (1–9 scale)	Malformation (1–9 scale)	Health (1–9 scale)
E. elata	14 defg	13 def	169 abcde		4.42 bcd	6.25 abcde	6.63 ab
E. maidenii	79 a	72 a	219 a	19.3	6.23 a	7.29 ab	7.06 a
E. bicostata	65 ab	53 ab	152 abcde	15.8	6.76 a	7.45 ab	6.94 ab
E. cinerea	4 g	4 f	183 abcd		3.00 de	4.00 e	5.25 bcd
E. camaldulensis	66 ab	41 bc	112 de				
E. stellulata	0 g	0 f					
E. tereticornis	39 bcdef	26 cdef	97 e				
E. ovata	45 bcde	33 bcde	168 abcde		4.12 cd	5.33 bcde	5.67 abcd
E. wilcoxii	21 defg	11 def	106 e		2.33 e	6.67 abcd	6.17 abc
E. macarthurii	47 abcd	37 bcd	130 cde		4.38 bcd	4.38 e	4.62 cd
E. globulus	57 abc	52 ab	208 ab	21.0	6.42 a	7.08 ab	4.00 d
E. botryoides	65 ab	52 ab	155 abcde		5.29 abc	4.68 de	4.88 cd
E. nitens (Vic)	31 cdefg	24 cdef	190 abc	16.7	5.50 abc	8.00 a	4.63 cd
E. nitens (NSW)	41 bcde	34 bcde	191 abc	17.8	5.62 abc	7.07 ab	6.73 ab
E. radiata	1 g	1 f	154 abcde				
E. nicholii	13 efg	10 ef	109 de				
E. saligna	67 ab	46 abc	109 de		5.87 ab	4.80 cde	5.80 abc
E. regnans	7 fg	6 f	164 abcde		6.43 a	7.43 ab	
E. fastigata	16 defg	9 ef	134 bcde		5.71 abc	7.00 abc	5.67 abcd
E. fraxinoides	0 g	0 f					

Tukey's multiple range test: means without following letters in common, differ significantly

Deane et Maiden all survived less than 13% on average, and had to be eliminated from any further consideration. *Eucalyptus camaldulensis* Dehnh. and *E. saligna* survived better (40% and 44%), but grew poorly with mean diameters of 112 and 109 mm. Diameter growth of *E. tereticornis* Smith and *E. macarthurii* Deane et Maiden was poor (97 and 130 mm) despite adequate survival, and these species can also be eliminated from serious consideration. The poor survival of many species on this site was undoubtedly attributable to the extraordinary site conditions of water-logging which caused mortality then, and later, due to shallow root systems, resulted in drought death and windthrow.

Of the other species, *E. globulus*, *E. maidenii*, *E. bicostata*, *E. nitens* (Vic and NSW), *E. ovata* Labill., and *E. botryoides* remained in the running. Of these, *E. maidenii* was clearly growing best, with mean dbh of 219 mm, survival of 72%, and health score of 7.06 which made it the healthiest species on this rather peculiar site. *Eucalyptus globulus*, ranking second, had a mean dbh of 208 mm and survival of 52%, but its mean health score was 4.00 and its survival, health, and growth were clearly declining rapidly. *Eucalyptus nitens* from Badja in southern NSW ranked third (equal to *E. nitens* (Vic)) with a mean dbh of 191 mm, survival of 34% (half that of *E. maidenii*), and a health score of 6.73. *Eucalyptus nitens* of Victorian origin (a mix of Rubicon, Mt Gwinear, and Macalister provenances) had grown well but survival was 24% and crown health was poor (4.63), and this seedlot was showing problems similar to those of *E. globulus*, including frequent recent windthrow of shallow-rooted trees. *Eucalyptus bicostata* had grown rather slowly (dbh 152 mm), but survival was good (53%) as was crown health (6.94). The assessments from the unreplicated 48-tree blocks generally followed the same trends as in the replicated trial (Table 11).

TABLE 11—Clive: Seedlot means for unreplicated 48-tree blocks

Species	Code	Survival (%)	Diameter (mm)	Straightness (1–9 scale)	Malformation (1–9 scale)	Health (1–9 scale)
E. nitens (Vic)	13	19	192			
E. nitens (NSW)	14	52	161	5.50	7.50	6.75
E. globulus	11	46	163			
E. maidenii	2	88	184	6.86	8.54	7.04
E. bicostata	3	29	138	6.83	8.00	6.50
E. ovata	8	73	131	3.79	5.93	6.14
E. botryoides	12	73	148	5.14	6.00	5.29
E. saligna	17	81	116			

On this site at age 11 years, with initial stocking of 5000 stems/ha, *E. maidenii* was able to maintain high survival (it was 88% in the unreplicated block) and carry a very high basal area (280 m^2/ha averaged over row plots and large block)*, as evidenced by its higher dbh than the other fast-growing species which were at much lower stockings, i.e., *E. nitens* and *E. globulus*. If this characteristic was also expressed under normal site conditions, it would be a valuable attribute for pulpwood production. *Eucalyptus maidenii* is clearly adapted to growth under conditions of high water table, with resultant shallow rooting, and did not suffer any serious defoliation from insect pests or fungal diseases.

* Because of high survival relative to its neighbours in the *E. maidenii* row plots and block plantations, favourable edge effects undoubtedly inflated the basal area.

Wood basic density (Tables 8 and 9) of *E. nitens* (Vic), *E. nitens* (NSW), *E. globulus, E. maidenii*, and *E. bicostata* was similar to that of these species at Kaikohe. In the breast-height increment-core study at age 9, densities were 10 to 20 kg/m³ higher than at Kaikohe, which was a small difference considering their respective ages of 5 and 9 years. The whole-tree values (Table 9) from the disc study at age 10 were 449, 489, and 582 kg/m³ respectively for *E. nitens*, *E. globulus*, and *E. maidenii*. The slower-growing *E. bicostata* had a density nearly the same as *E. maidenii* in the increment-core study. A further five trees sampled by discs (M.McConchie, unpubl. data) gave whole-tree weighted mean densities of 604 kg/m³ (585–636 kg/m³) for *E. maidenii* and 470 kg/m³ (454–506 kg/m³) for *E. globulus*.

The good growth of *E. globulus* on the Hawke's Bay site and good health up until recently (when the effects of the high water table have probably taken effect) promises well for this species in this climate. It is tempting to hypothesise that the hot dry summer climate of Hawke's Bay, and that of the Wairarapa region to the south and Poverty Bay to the north, may be better suited to growing some eucalypts, particularly *E. nitens* (Vic) and *E. globulus*, both winter-rainfall provenances/species, than the climates of Northland and the Bay of Plenty with their more evenly distributed rainfall .

Patoka

The outplanting of three species at Patoka—*E. nitens* from central Victoria, *E. maidenii*, and *E. bicostata*—provided a valuable qualitative check of the performance of the same seedlots as were planted at Clive, under more typical forest site conditions for the region.

All three species showed excellent health, little evidence of fungal leaf disease, and only minor insect defoliation, probably by *Paropsis charybdis* Stål. Growth of *E. nitens* was rapid, with a stand mean height of 24.9 m at age 11 years and mean dbh of 432 mm (at a stocking of 170 stems/ha) (Table 12). This was a spectacular young stand, managed for sawlogs, which could well exceed 500 mm dbh by age 15 years and which showed every prospect of continued healthy growth. However, its breast-height core basic density (Table 7) was quite low (436 kg/m³).

Eucalyptus maidenii, in comparison, was 2 m shorter (22.5 m) in height and smaller in dbh (356 mm) than the *E. nitens*. Some of this inferiority in dbh could be attributed to later thinning of this species from 300–400 stems/ha to 170 stems/ha. Crown health was excellent and the crown was denser than that of *E. nitens*, resulting in less light beneath the canopy. Bole straightness was a little inferior to that of *E. nitens*; *E. maidenii* develops heavier branches at these stockings and, as a result, crowns are more subject to wind damage. Its wood density was much higher than that of *E. nitens* (500 kg/m³).

TABLE 12–Patoka: Species transect means

Species	Height (m)	Diameter (mm)	Straightness (1–9 scale)	Malformation (1–9 scale)	Health (1–9 scale)
E. nitens (Vic)	24.9 a	432 a	8.08 a	8.08 a	7.04 b
E. maidenii	22.5 b	356 b	7.50 b	7.88 a	7.54 a
E. nitens (Vic)	24.9 a	430 a	8.20 a	8.67 a	7.08 b
E. bicostata	16.8 b	299 b	7.71 a	7.08 b	7.54 a

Means without letter in common differ significantly ($p < 0.05$)

Eucalyptus bicostata showed good bole straightness and excellent crown health, but was substantially slower-growing in height (16.8 m) and dbh (299 mm) than the other species. Its wood density (Table 7) was slightly higher than that of *E. maidenii*, and both species were much higher than *E. nitens*, but not as much so as at Clive.

CONCLUSIONS

The trials at Kaikohe and Clive were located on quite different sites, the Clive site being clearly atypical. The serious mortality and health problems at the Kaikohe site with the Victorian provenances of *E. nitens* and with *E. globulus* may not be typical of Northland sites. However, the much better survival and crown health of the southern NSW provenances of *E. nitens* at both sites is a notable result and this finding seems likely to be borne out in other plantings in the Bay of Plenty and Northland.

The trials at the three sites reported here are the only known plantings of *E. maidenii** in New Zealand where comparisons can be made with *E. nitens* and *E. globulus* (apart from some very recent planting in the Bay of Plenty by Tasman Forest Industries). There is also a dearth of information on *E. globulus*, and the Kaikohe and Clive trials, together with the 1993 trial at Omataroa in the Bay of Plenty, are the only successful recent trials with this species, apart from some recent industry planting. Information is generally lacking on the relative performance of eucalypt species on the East Coast of the North Island, particularly for *E. globulus* and *E. maidenii*.

The results highlight the need for further provenance testing of *E. globulus* and *E. maidenii,* and new trials are to be planted in 1999. The results also demonstrate the major genetic differences between these related species in all traits, from wood properties to growth and health, and this seems to accord much better with their original status as separate species rather than as subspecies. Also highlighted are the important differences between the New South Wales populations of *E. nitens* and those from central Victoria, and that of *E. denticulata* from the Errinundra plateau. There appears to be a good case for developing a future breeding programme for the southern NSW populations for application in warm humid climates in New Zealand.

The superior kraft pulping properties of *E. globulus* are well known, though little work has been done yet on New Zealand-grown material. It gives a premium market kraft pulp in Portugal (Kibblewhite *et al.* 1991) and it is the preferred species for planting in export chip programmes in Australia and South America. Although little is known about pulping properties of *E. maidenii*, its substantially higher wood density than *E. globulus* (and *E. nitens*) in these trials, its high density at a young age, and its ability to maintain high stocking and high basal area make it an interesting prospect for growing on short rotations for kraft pulping. It is reported to have been grown successfully in Argentina where there has been a recent expansion in its planting (L.D.Gea, pers. comm.) and it is much planted in Yunnan province in China (M.D.Wilcox, pers.comm.).

The better health of *E. maidenii* (distribution confined to south-eastern New South Wales) than of the related *E. globulus* (from Tasmania, Bass Strait islands, and the south coast of

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* At the recently-assessed trial at Carnation Road in Kaikohe (*see* footnote p. 276) the relative performance of *E. nitens* provenances and of *E. globulus* and *E. maidenii* was very similar to that at Knudsen Road, nearby.

Victoria), and of *E. nitens* provenances from New South Wales than from central Victoria, observed in these trials, leads one to hypothesise that eucalypt species and provenances from areas in New South Wales with evenly-distributed or summer rainfall climates may be better adapted to many North Island sites than species and provenances from latitudes that are similar to New Zealand yet have more Mediterranean climates (winter rainfall, summer drought) such as those of Tasmania, Victoria, South Australia, and Western Australia. The good health and adaptability of *E. fastigata* (from southern highlands and northern tablelands of New South Wales), several stringybark species, and *E. pilularis* Smith from New South Wales (Wilcox 1998) appear to support this idea.

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REFERENCES

JOHNSON, G.R.; WILCOX, M.D. 1989: *Eucalyptus* species trials on pumiceland. *New Zealand Forestry 34(1)*: 24–27.

KIBBLEWHITE, R.P.; BAWDEN, A.D.; HUGHES, M.C. 1991: Hardwood market kraft fibre and pulp qualities. *Appita 44(5)*: 325–332.

KIRKPATRICK, J.B. 1975: Natural distribution of *E. globulus* Labill. *Australian Geographic 13*: 22–35.

WILCOX, M.D. 1998: Ian Brooker and eucalypts: Stimulating visit by Australian eucalypt specialist. *Tree Grower 19(2)*: 19–22.

WILCOX, M.D.; MILLER, J.T.; WILLIAMS, I.M.; GUILD, D.W. 1985: *Eucalyptus* species trials in Longwood Forest, Southland. *New Zealand Forest Service, FRI Bulletin No.95.*