EUCALYPTS FOR NORTHLAND: 7- TO 11-YEAR RESULTS FROM TRIALS OF NINE SPECIES AT FOUR SITES

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(Received for publication 5 May 2000; revision 24 August 2000)

ABSTRACT

Species and provenance trials of eucalypts planted in Northland between 1988 and 1993 included several provenances each of *Eucalyptus fastigata* Deane et Maiden, *E. regnans* F. Mueller, *E. saligna* Smith, *E. botryoides* Smith, *E. grandis* Hill ex Maiden, *E. nitens* (Deane et Maiden) Maiden, *E. globulus* Labill, and *E. maidenii* Labill. Trials were all located between Kaikohe and Dargaville (latitudes 35°31′ to 35°48′), with two trials at Carnation Road and two at Walker Road (aged 11 and 9 years) and one of *E. nitens* only at Karaka Road.

Trial designs were mainly 64-tree square plots with two to five replicates. Trees were assessed for breast height diameter over-bark, bole straightness, malformation, and crown health. Results were expressed as provenance and species means at each site, and also as basal area per hectare over-bark, volume per hectare under-bark, and frequencies of crop trees, mortality, and runts (suppressed sub-dominants).

Eucalyptus fastigata at its single test site showed best growth and health of all species (mean annual increment (MAI) at Carnation Road averaged 52 m^3/ha) but suffered some basal and upper stem forking. *Eucalyptus regnans* averaged 50 m^3/ha/year, with good crown health, but *E. nitens* of central Victorian provenances showed poor crown health and high mortality despite good earlier growth. *Eucalyptus saligna* (and *E. grandis*) grew more slowly than other species and showed a high frequency of runts. *Eucalyptus maidenii*, planted in only one subsidiary trial at Carnation Road (and at Knudsen Road), had better crown health, higher survival, and better growth than *E. saligna, E. grandis,* and *E. globulus*, though its volume growth appeared to be less than *E. fastigata* in the main trial.

Eucalyptus nitens of central Victorian provenances was evidently poorly adapted and unlikely to continue its earlier good growth, and even the healthier NSW provenances appeared insecure. *Eucalyptus fastigata* was a clear winner for growth and health, followed by *E. regnans*. *Eucalyptus globulus* had generally poor health and slower growth than *E. nitens*. *Eucalyptus maidenii*, although a slower starter, had good crown health and good survival, and showed higher wood density (from other studies) than

E. nitens and *E. globulus*, and by inference, *E. fastigata* and *E. regnans*. *Eucalyptus saligna*, originally the preferred species in Northland, produced much less volume than the other species. *Eucalyptus botryoides* failed completely due to early possum damage.

Keywords: provenance; Northland; growth; form; density; *Eucalyptus nitens*; *Eucalyptus fastigata*; *Eucalyptus regnans*; *Eucalyptus globulus*; *Eucalyptus maidenii*; *Eucalyptus saligna*; *Eucalyptus grandis*.

INTRODUCTION

In 1981, afforestation was begun in Northland, New Zealand by New Zealand Forest Products Ltd (later Carter Holt Harvey Forests Ltd). Initially, only *Pinus radiata* D. Don was planted, but in 1985 it was proposed that the "Mangakahia Project" should include up to half its area in eucalypts to provide short-fibred pulp for a planned kraft pulp mill (P.J.Smale unpubl. data). A series of eucalypt establishment trials as well as species and provenance trials was initiated by Paul Smale (for New Zealand Forest Products) in 1986. That year and in 1987 some establishment trials were undertaken with *E. saligna* and *E. regnans*. *Eucalyptus saligna* was traditionally the main species grown for shelter, amenity planting, and timber production in Northland on better sites, while *E. botryoides* had been used on wetter sites. Earlier trials by New Zealand Forest Products in the 1970s had also shown *E. saligna* to be the best species (H.McKenzie unpubl. data). *Eucalyptus regnans* was included and later *E. fastigata* as the species with which the company had successfully established a large pulpwood resource of some 7000 ha in the central North Island, near Tokoroa. For various reasons, commercial-scale eucalypt planting by Carter Holt Harvey was shelved and no pulp mill has been constructed in Northland.

There were, initially, some problems with survival, especially with *E. regnans* and *E. fastigata* on wet clay soils. By 1988 establishment techniques, including ripping and bedding or v-blading, fertiliser treatment, and weed control by herbicides had been worked out, and *E. saligna* was still appearing as the most suitable eucalypt species for Northland. The species and provenance trials, initiated in 1987 and planted in 1988, fortunately included *E. regnans* and *E. fastigata* as well as *E. saligna* and *E. botryoides*. "New" species to the region that were included in the trials were *E. nitens*, *E. globulus*, *E. maidenii*, and *E. grandis*. Species and provenance trials were planted at Carnation Road (two trials) and at Karaka Road in 1988, at Walker Road (two trials) in 1990, and at Knudsen Road in 1991 (previously reported by Low & Shelbourne 1999). An assessment of the Carnation Road and Walker Road trials at ages 11 and 9 years respectively is reported here (*E. nitens* only was also assessed at Karaka Road).

MATERIALS AND METHODS

Trials and Seedlots

In all, 20 seedlots from eight species were tested in two nearly adjacent trials at Carnation Road (planted 1988), 10 seedlots from three species in two adjacent trials at Walker Road, (planted 1990), and 26 seedlots of seven species at Knudsen Road (planted 1991) (Table 1). A replicate of Carnation Road Trial 1 was planted at Karaka Road. Code numbers, seedlot numbers where available, and their provenance or origin are listed in Table 2; their natural distributions in Australia are shown in Fig. 1 (Orme 1977; Boland *et al.* 1984; Tibbits & Reid

TABLE 1a–Information on sites

Site information	Carnation Road Trial 1	Carnation Road Trial 2	Karaka Road	Walker Road Trial 1	Walker Road Trial 2	Knudsen Road
Latitude	35°34′	35°34′	35°44′	35°48′	35°48′	35°31′
Longitude	173°46.5′	173°46.5′	173°54.5′	173°54′	173°54′	173°49′
Altitude (m)	195	195	135	75	75	180
Mean annual rainfall (mm)	1917	1917	1623	1458	1458	1773
Mean annual temperature (°C)	14·24	14·24	14·40	14·68	14·68	14·43
Aspect	N	N				Varied
Slope	Gentle	Ridgetop	Flat	Mod. Slope	Mod. Slope	Varied
Exposure	Sheltered	Exposed	Sheltered	Sheltered	Sheltered	Sheltered
Soil	Waimatenui clay	Waimatenui clay	Waiotira clay loam	Waiotira clay loam	Waiotira clay loam	Clay with volc. ash
Cultivation	V-blade	V-blade	V-blade	V-blade	V-blade	?
Date planted	6/88	11/88	7/88	7/90	9/90	/91
Design*	RCB	RCB	RCB	RCB	RCB	RCB
Plot size (ha)	0.025	0.016	0.025	0.045	0.045	0.019
Plot dimensions (m)	16×16	8×20	16×16	16×28	16×28	14×13
Number of trees/plot	64	20	64	64	64	49
Stocking	2500	1250	2500	1430	1430	2631
Thinning (age 2)	1250	–	1250	–	–	1316

TABLE 1b–Allocation of species and seedlots

Species/provenance group	Number of seedlots					
E. saligna	5	1 (bulk)	5	1	1	6
E. fastigata	3		3			
E. regnans	4		4			
E. nitens						
Northern NSW				1		1
Southern NSW	1		1	1	1	3
Victoria	2		2	1	2	6
E. denticulata						1
E. botryoides	1		1			2
E. globulus		1		1	1	2
E. maidenii		1				2
E. grandis		1				3

* RCB = randomised complete blocks

1987). The seedlots were chosen as those that were available at the time and do not represent a proper sampling of the range of each species. An exception to this would be the good provenance sample for *E. nitens* at Knudsen Road.

At Carnation Road Trial 1, *E. saligna* was represented by two seedlots from natural populations in New South Wales (NSW) (Bateman's Bay and Kangaroo Valley) which had performed well in a 1976 *E. saligna* provenance trial (C.B.Low unpubl. data). For *E. fastigata*, only one native provenance (from the southernmost part of the range in eastern Victoria) was

TABLE 2–List of seedlots

Species	Code	Seedlot No.	Provenance/origin	No. Parents
Carnation Road Trial 1				
E. saligna	S1	ex GTI §	Batemans Bay, NSW	
	S2 *	ex GTI	Waitangi, NZ	
	S3 †	89/3	Seed orchard NZ	9
	S4	ex GTI	Kangaroo Valley, NSW	
	S5	1/0/86/27	Waipoua, NZ, Cpt. 8/1	
E. fastigata	F1		Natal, S. Africa, ex Walkers Road, Kinleith	
	F2	8/0/87/38	Bendoc, Vic.	8
	F3	ex GTI	Oakura, NZ	
E. regnans	R1		Wilmot, Tas.	
	R2	2/2/86/32	Kinleith, NZ Atiamuri Seed Stand	57
	R3	ex GTI	Strzlecki, Vic.	
	R4	ex GTI	Seed orchard, NZ	
E. nitens	N1 ‡	ex GTI	NSW (Southern)	
	N2	8/0/87/31	Mt Toorongo plateau, Vic. (ex. Farrars)	
	N3	8/0/87/33	Mt Toorongo plateau, Vic. (ex. Alison Hort.)	
E. botryoides	B1	1/3/87/8	Woodhill seed orchard	
Carnation Road Trial 2				
E. grandis	Grandis	FRI77/2055	Francinus Rus, SA Forest Investments Ltd, Sabie, S. Africa S/N S467	
E. saligna	Saligna	Mixed		
E. globulus	Glob G	HO/0/77/19	Australian Seed Co. (L.J. Langley) ex California	
E. maidenii	Glob M	88/853	Waiohiki, Napier, NZ	4
Walker Road Trial 1				
E. nitens	N22 (GTI 2)	HO/68/723	Barrington Tops, N. NSW 31°59′S, 151°50′E, alt. 1520 m	
E. nitens	N63 (GTI 63)	HO/0/75/14	Anembo, Tallaganda, S.F. 35°48′S NSW alt. 1220 m	
	N Mix (GTI 81)	78/2147	Connors Plain, Licola, Vic, 37°32′S, 146°28′E, alt. 1310 m	1
	N Mix (GTI 105)	78/2152	Barnewell Plain, Vic. alt. 930 m	1
	N Mix (GTI 116)	78/2153	Mississippi, Powelltown, Vic. alt. 920 m	1
	N Mix (GTI 124)	HO/0/78/17	Blue Range, Taggerty, Vic. alt. 1100 m	
	N Mix (GTI 21)		Toorongo plateau, Vic. 37°36′S, 146°10′E, alt. 1066 m	1
	N Mix (GTI 23)		Toorongo plateau, Vic. 37°50′S, 146°13′E, alt. 854 m	1
	N Mix (GTI 95)	78/2150	Loch Valley, Noojee Forest District, Vic. 37°48′S, 146°04′E, alt. 960 m	1
	N Mix (GTI 98)	78/2151	Toolangi, Vic. 37°32′S, 145°34′E, alt. 600 m	1
E. saligna	S89	GTI -9/3	Tairua seed orchard	9
E. globulus	G89	GTI -89/264	Cygnet, Tasmania	
Walker Road Trial 2				
E. nitens	N32	89/725	Glentunnel NZ	
E. nitens	N33	90/110	Toorongo, Vic.	
E. nitens	N34	90/8	Cpt 905, Kaingaroa, NZ (ex Nimmatabel, S. NSW)	6
E. globulus	G31	88/231	Jeeralang, Vic.	
E. saligna	S31	89/3	Tairua seed orchard	9

* S2 = Mix of SA 128 (stand) 8.8 g and SA 124 (single tree) 1.3 g
† S3 = Half from FRI and half from Kaueranga seed orchards
‡ = Mix of Tallaganda 10 g, Nimmatabel 6 g, Bondi 5 g
§ = Provided by Genetics and Tree Improvement, New Zealand Forest Research Institute

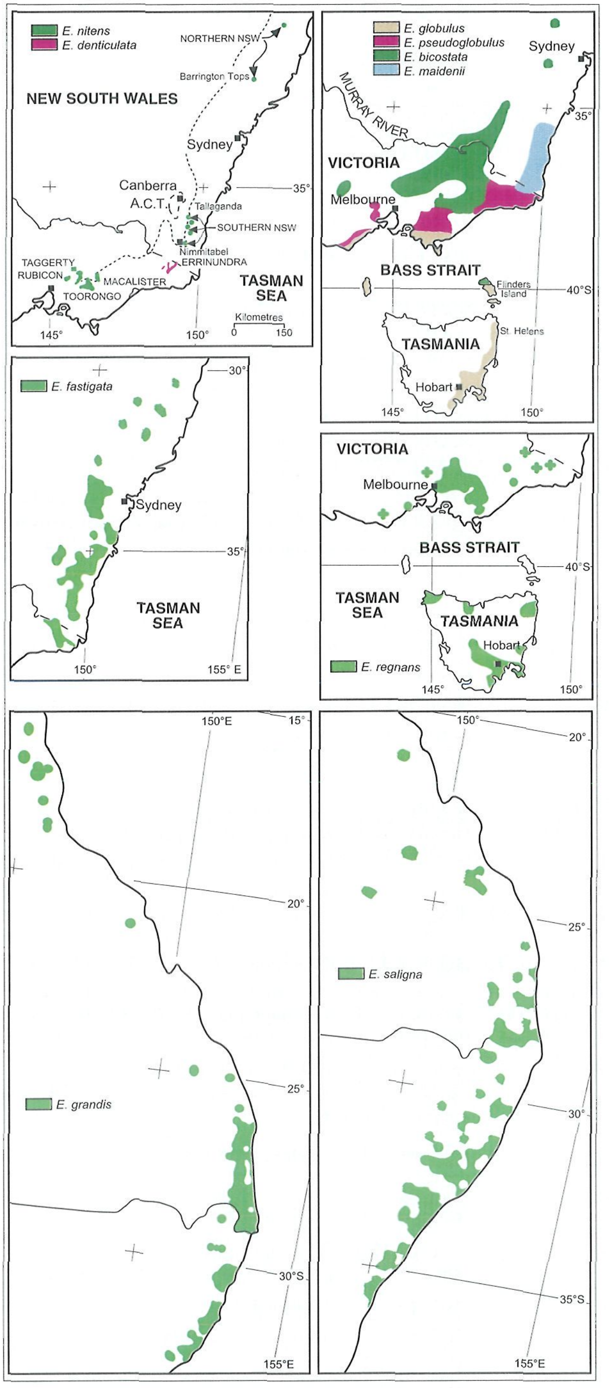

FIG. 1–Natural distributions of *Eucalyptus bicostata, E. denticulata, E. fastigata, E. globulus, E. grandis, E. maidenii, E. pseudoglobulus, E. regnans,* and *E. saligna* (after Boland *et al.* 1984; Orme 1977; Tibbits & Reid 1987).

represented and this had performed in a mediocre way in a 1980 provenance trial in the central North Island (F.Burger unpubl. data). *Eucalyptus regnans* was represented by one seedlot each from Tasmania and Victoria, as well as seedlots from selected parents in the Wiltsdown (Tokoroa) provenance trial of 1976, and from a New Zealand clonal seed orchard. *Eucalyptus nitens* seedlots included one from NSW (a mixture of seed from southern NSW populations at Tallaganda, Nimmatabel, and Bondi), and two different lots from Toorongo in central Victoria. *Eucalyptus botryoides* was represented by one seedlot from the Woodhill seed orchard.

The seedlots of *E. grandis*, *E. globulus,* and *E. maidenii* in Trial 2 at Carnation Road were all from exotic stands for which there is no provenance information, and the *E. saligna* seedlot was a bulk of all *E. saligna* lots in Trial 1. At Walker Road, the *E. nitens* provenances included one each from Barrington Tops, NSW (the second-most northerly population, latitude 34°S), Mt Anembo (Tallaganda S.F.), Nimmatabel (ex Cpt. 905, Kaingaroa, New Zealand) in the southern NSW group, from Toorongo, central Victoria, and from a mix of eight central Victoria provenances. The New Zealand seedlot originated from a small stand of Victorian provenance at Glentunnel, Canterbury, whose offspring provided the seedlot used in the trial, which was possibly inbred. The two *E. globulus* provenances at Walker Road included one from southern Tasmania and one from Jeeralang, Victoria, in the north-eastern margin of the *E. globulus* distribution where it adjoins and can hybridise with *E. pseudoglobulus* Labill. The *E. saligna* seedlot in the Walker Road trials was from the New Zealand Tairua seed orchard.

Sites

Carnation, Karaka, Walker, and Knudsen Road trials are located south of Kaikohe, longitude 173°48′E, latitude 35°24′S (Table 1). The Carnation Road site is at altitude 150 m, and the soil is a Waimatenui clay; at Walker Road, altitude 50 m, and Karaka Road, altitude 100 m, the soil, is a Waiotira clay loan. Knudsen Road, at altitude 150 m has a clay soil with a capping of volcanic ash in part of the area. Mean annual temperatures at these sites range from 14.2°C to 14.7°C, and mean annual rainfall from 1458 mm to 1917 mm, as derived from Bioclim (J.Leathwick, pers. comm.).

Design and Layout

The experimental design used in all the trials (Table 1) was randomised complete blocks (RCB) with two or five replications which were generally balanced, except where poor survival necessitated rejection of a few plots. Plot size was 64 trees (8 × 8 rows) at Carnation Road Trial 1, Karaka Road, and Walker Road Trials 1 and 2; 20 trees (2 × 10 rows) in Carnation Road Trial 2; and 49 trees (7 × 7 rows) at Knudsen Road. Spacing was 2 × 2 m (2500 stems/ha) at Carnation Road Trial 1 and Karaka Road, and 2 × 1.9 m at Knudsen Road (2632 stems/ha), all three trials being thinned at age 2 years to half stocking. The Walker Road trials were planted at between 3 and 4 × 2 m (average stocking , about 1450 stems/ha) and were not thinned and neither was the Carnation Road Trial 2 at 4 × 2 m spacing (1250 stems/ha). All surviving trees were measured or assessed but basal area and volume per hectare were estimated, based both on whole plots and on inner plots created within a single buffer row at the Carnation Road Trial 1, Karaka Road, and Walker Road trials.

Assessments

The same assessment procedure was used in all trials. Each tree position was scored as applicable, as a missing tree, a dead tree, or a runt (a tree that was well below the canopy in height and with a diameter at breast height over-bark (dbh) less than 120 to 150 mm, depending on species). All remaining trees were measured for dbh, and subjectively scored for bole straightness (1 = very crooked to 9 = straight), malformation (1 = multiple forks to 5 = single stem) and crown health and density (1 = almost leafless to 9 = long dense crown of undamaged leaves).

Between 20 and 30 trees of *E. globulus* and *E. maidenii* (in Trial 2) and *E. nitens* (southern NSW) in Trial 1 at Carnation Road and at Knudsen Road were increment-core sampled for breast-height outer-wood basic density, as part of tree selection for a kraft pulp and wood properties study.

A 10-tree sample of top height trees of each species was measured at Carnation Road in both Trials 1 and 2.

Analysis

The presence/absence data on missing and dead trees, and runts, were variously expressed as seedlot mean percentages of "crop trees", "early mortality and thinnings", "later mortality", and "runts" (which were not assessed for anything else). Individual-tree values for dbh, straightness, malformation, and health scores were analysed directly and dbh of individual trees was converted to basal area, summed per plot, and expressed as basal area per hectare. Volume equations, devised for *E. regnans*, *E. fastigata,* and *E. saligna* (Smart 1992; Gordon *et al.* 1995) were used to calculate volume per hectare for appropriate seedlots, and the equation for *E. regnans* was used for the remaining species. Basal area and volume per hectare were also calculated for the inner plots, to eliminate competition effects as far as possible.

The trial designs were all randomised complete block designs. However, in Carnation Road Trial 2 and at Karaka Road single seedlots represented each species, while in the other trials each species consisted of several seedlots. The equation for the model of a randomised complete block design with species and provenances within species is as follows:

$$Y_{ijk} = \mu + S_i + R_j + P_k : S_i + E_{ijk}$$

where Y_{ijk} = the observation on the ith species in the jth rep of the kth seedlot
μ = the overall mean
S_i = the effect of the ith species
R_j = the effect of the jth replicate
$P_k : S_i$ = the effect of the kth seedlot within the ith species
E_{ijk} = the random error associated with each tree of the kth seedlot in the ith species in the jth replicate

In theory the model would also include interactions between species and replicate, and between seedlot and replicate. The model containing interactions was tried, but as the interactions were not significant, they were omitted from the model.

The following model was used to analyse Carnation Road Trial 2 and Karaka Road, and with the other trials to analyse seedlots irrespective of species:

$$Y_{ij} = \mu + P_i + R_j + E_{ij}$$

where Y_{ij} = the observation on the i^{th} seedlot in the j^{th} rep
μ = the overall mean
P_i = the effect of the i^{th} seedlot
R_j = the effect of the j^{th} replicate
E_{ij} = the random error associated with each tree of the i^{th} seedlot in the j^{th} replicate

The data were analysed using PROC GLM of the SAS software package. Species were treated as fixed, while replicates and seedlot within species were treated as random effects. The Tukey's multiple range test option was used to show significant differences between species means. The data were also analysed without the species classification as there was some overlap in performance, revealing significant differences between seedlot means, regardless of species.

RESULTS AND DISCUSSION

Carnation Road Trial 1

Seedlot mean percentages for crop trees, early mortality and thinnings, later mortality, runts, and basal forks are listed in Table 3, which gives a picture of the stand in terms of survival and development of competitional effects. About 50% of the trees were reportedly removed in a very early thinning (age 2 years). In most seedlots early mortality plus thinnings came close to this figure, apart from severe early mortality in *E. regnans* seedlot R4. Later mortality, recorded by scoring dead trees, was quite variable but was particularly severe in *E. nitens* N2 from Toorongo, Victoria, and *E. regnans* R4 from the New Zealand seed orchard. *Eucalyptus fastigata* from Bendoc, Victoria, also showed 14% later mortality. Survival of *E. botryoides* was so low that these plots were not assessed; early possum damage was severe and may have caused the failure of this species (P.Smale unpubl. data).

The frequency of runts was species-dependent and highest in all the *E. saligna* seedlots, averaging 26%. The plots of *E. saligna* contained a few healthy, well-grown individuals and a large proportion of co-dominant and suppressed stems that contributed to the "runt" category. Basal forking was almost absent in *E. saligna*, relatively low in *E. nitens* and *E. regnans* (6%), but high in *E. fastigata* (22%).

Crop tree percentages differed substantially between species, reflecting the differences in the other frequency traits. *Eucalyptus fastigata* averaged 43% and *E. saligna* 23% of crop trees from the original number planted, with *E. nitens* and *E. regnans* intermediate. These frequencies of crop trees have an important influence on both mean dbh and volume per hectare of different seedlots. There was major variation among the seedlots of *E. nitens*, with one Toorongo seedlot (N3) well stocked and the other (N2) poorly stocked owing to recent mortality.

Growth rate is expressed (Table 3) as mean dbh (over-bark), basal area per hectare (over-bark), and volume per hectare (under-bark). Volume is likely to be over-estimated for *E. maidenii* as the *E. regnans* equation used to calculate its volume did not take account of its very thick bark. Runts were included in basal area and volume per hectare, but contributed very little. Mean dbh of all *E. saligna* seedlots was clearly well below that of the other three species, averaging 240 mm; dbh of *E. nitens* was lower than that of *E. fastigata* and *E. regnans*, with *E. fastigata* averaging 315 mm across all provenances.

TABLE 3–Carnation Road Trial 1 species and provenance means and F tests

Species and origin	Crop† trees (%)	Early mortality and thinning (%)	Later mortality (%)	Runts (%)	Basal forks (%)	Height (m)	Dbh (mm)	Basal area (m^2/ha) Whole	Basal area (m^2/ha) Inner	Volume (m^3/ha) Whole	Volume (m^3/ha) Inner	Bole straightness (1–9)	Malformation (1–5)	Crown health (1–9)
E. fastigata														
F1 Kinleith, NZ	43 a	51 a	0 a	5 abc	21 bc		299 abc	82 b	69 abc	627 bcd	518 abcd	5.3 bcd	4.0 bcd	6.1 ab
F2 Bendoc, VIC	41 a	38 a	14 abc	7 abc	25 c		301 abc	80 b	73 ab	609 bcde	542 abcd	6.4 ab	3.7 de	5.1 abcd
F3 Oakura, NZ	44 a	51 a	2 abc	3 ab	21 bc		345 a	111 a	87 a	879 a	668 a	5.8 abcd	3.9 cd	6.2 a
Mean	**43 a**	**47 a**	**6 a**	**5 a**	**22 b**	**27.5**	**315 a**	**91 a**	**76 a**	**705 a**	**576 a**	**5.8 b**	**3.9 b**	**5.3 a**
E. nitens														
N1 Southern NSW	34 abcd	50 a	8 abc	8 abc	13 abc		286 cde	60 cde	48 cde	586 bcde	465 abcdef	6.3 abc	4.6 a	5.0 abcde
N2 Toorongo, VIC	26 bcde	54 a	20 bc	1 a	0 a		292 bcd	45 def	41 de	441 defg	401 bcdef	7.1 a	4.8 a	3.8 fg
N3 Toorongo, VIC	40 a	51 a	6 abc	4 abc	5 abc		248 def	52 cdef	49 cde	496 cdef	468 abcdef	6.9 a	4.4 abc	3.4 g
Mean	**33 b**	**51 a**	**11 a**	**4 a**	**6 a**	**25.5**	**273 b**	**52 b**	**46 c**	**508 e**	**445 b**	**6.8 a**	**4.6 a**	**4.1 b**
E. regnans														
R1 Wilmot, TAS	34 abcd	48 a	8 abc	10 bc	8 abc		307 ab	69 bc	66 abc	679 abc	645 a	6.3 abc	4.3 abc	5.6 abc
R2 Atiamuri, NZ	38 ab	49 a	4 abc	9 abc	7 abc		284 bcde	65 bcd	61 cde	639 bcd	587 abc	6.9 a	4.4 abc	4.9 cdefg
R3 Strzlecki, VIC	36 abc	51 a	1 ab	12 c	4 abc		306 ab	74 bc	63 bc	730 ab	617 ab	7.0 a	4.5 ab	5.9 ab
R4 NZ Orchard	15 e	61 a	21 c	4 abc	3 ab		328 ab	35 f	35 e	357 fg	362 def	6.9 a	4.1 bcd	5.5 abcd
Mean	**31 b**	**52 a**	**8 a**	**8 b**	**6 a**	**27.4**	**306 a**	**61 b**	**56 b**	**601 b**	**553 a**	**6.8 a**	**4.3 a**	**5.5 a**
E. saligna														
S1 Batemans Bay, NSW	18 e	51 a	3 abc	28 d	0 a		237 ef	29 f	29 e	267 g	268 f	4.8 d	3.0 g	3.6 fg
S2 Waitangi, NZ	24 cde	48 a	3 abc	25 d	2 ab		243 def	36 f	34 e	337 fg	317 ef	5.1 bcd	3.4 efg	3.6 g
S3 Seed Orchard NZ	25 bcde	48 a	1 ab	25 d	0 a		232 f	35 f	35 e	320 fg	326 def	5.0 cd	3.1 fg	4.3 cdefg
S4 Kangaroo valley, NSW	23 de	48 a	2 abc	27 d	2 ab		237 ef	34 f	32 e	315 fg	294 ef	4.9 d	3.5 def	4.3 cdefg
S5 Waipoua NZ	26 bcde	48 a	2 abc	23 d	0 a		251 cdef	41 ef	39 de	383 efg	365 cdef	5.0 cd	3.2 efg	4.6 cdefg
Mean	**23 c**	**49 a**	**2 a**	**26 c**	**1 a**	**24.7**	**240 c**	**35 c**	**34 d**	**324 d**	**314 c**	**5.0 c**	**3.2 c**	**4.1 b**
F tests for species	5.55*	0.99	1.43	58.76***	35.41***		10.66***	13.15***	14.91***	7.95**	9.35**	11.53***	27.53***	9.48**
F tests for seedlots	13.86***	1.49	3.27**	35.86***	5.74***		13.69***	26.90***	15.88***	16.67***	9.31***	11.37***	30.01***	15.93***

† Seedlot mean percentages
Letters following a mean were produced by Tukey's multiple range test. Means not sharing a letter are considered to be significantly different.

Basal area and volume per hectare were highest for *E. fastigata*, followed by *E. regnans* and then *E. nitens*. The volume production of *E. saligna* was only half that of *E. fastigata*. Considering the more conservative volume per hectare figures based on the inner plots, the best *E. fastigata* seedlot from Oakura, New Zealand, showed a mean annual increment (MAI) of 61 m^3/ha. Mean annual increments for *E. fastigata*, *E. regnans*, *E. nitens*, and *E. saligna* averaged 52, 50, 40, and 29 m^3/ha respectively. Excluding the aberrant *E. regnans* seedlot R4 which had heavy early mortality, the average MAI for *E. regnans* was 56 m^3/ha. These figures for *E. fastigata* and *E. regnans* are encouragingly high for a heavy clay soil in Northland.

There was important variation between seedlots within *E. fastigata* (and the other species) but this is only suggestive of the possibilities of gain in growth rate from provenance testing and breeding.

Eucalyptus saligna had the poorest bole straightness of all species (Table 3) and the lowest malformation scores, reflecting the high incidence of top breakage and subsequent forking and stem deformation, probably caused by wind and possums. Bole straightness scores were lower for *E. fastigata* than for *E. nitens* and *E. regnans,* as were malformation scores, because of forking (there was also a high frequency of basal forks in *E. fastigata*).

Crown health was good for *E. fastigata* but the Bendoc, Victoria, provenance averaged only 5.1 *vs* 6.1 for the other two seedlots. Crown health was poor in the two Toorongo, Victoria, seedlots of *E. nitens* (3.4 and 3.8) and better in the southern NSW provenance (5.0), as apparent also in the Knudsen Road trial (Table 4). The low crown health scores combined with high mortality in the Victorian seedlots resulted in sick-looking stands. Crown health scores for *E. regnans* were good but poor for *E. saligna*, possibly reflecting damage by the gallwasp, *Ophelimus* spp.

TABLE 4–Knudsen Road species and provenance means

Species and origin	Code number	Crop trees (%)	Dbh (mm)	Basal area (m^2/ha)	Bole straightness (1–9)	Malformation (1–9)	Crown health (1–9)
E. nitens Barrington Tops, NNSW	NN48	48	177	34	8.0	8.3	6.0
E. nitens southern NSW		46	200	40	6.4	8.1	5.6
E. denticulata Errinundra, VIC	NN44	43	163	25	6.6	7.6	4.8
E. nitens central VIC		21	201	19	7.5	8.2	3.4
E. globulus		33	170	21	6.1	6.8	3.2
E. maidenii		46	174	30	6.6	7.3	6.5
E. grandis		44	191	30	6.4	5.7	6.5
E. saligna		44	163	26	6.7	6.2	6.2
E. botryoides		34	141	16	5.7	5.1	4.3

Carnation Road Trial 2

No thinning was done in this trial, and so crop tree percentage represents relative survival or stocking of dominant and co-dominant trees (Table 5). *Eucalyptus maidenii* had best survival of all four species (80%) with 14% deaths and few runts. *Eucalyptus saligna*, and to a lesser extent *E. grandis*, had a high proportion of runts as was typical of *E. saligna* in Trial 1. *Eucalyptus globulus* displayed the worst mortality of all species, which appeared to be continuing, and health score was very low (3.0).

Height growth was similar for all species (Table 5), but *E. saligna* (a bulked lot of all seedlots represented in Trial 1) was 3 m shorter than in Trial 1 (21.7 m), indicating a difference in site quality between the two trials. Direct comparisons of volume and basal area per hectare of species in Trial 2 with those in Trial 1 will thus be biased. Because small (20-tree) plots were used in Trial 2, calculation of inner plot basal area and volume was impossible.

Eucalyptus maidenii, a single New Zealand seedlot with a narrow genetic base, exhibited the largest basal area per hectare and MAI of 43 m^3/ha at an actual stocking of 1000 stems/ha. *Eucalyptus globulus*, *E. saligna*, and *E. grandis* showed a similar crop tree stocking (about 60% or 750 stems/ha), similar dbh (212 mm), and MAI of 34 m^3/ha (*E. globulus)* and 36 m^3/ha (*E. grandis)*. From experience at Clive in Hawke's Bay (Low & Shelbourne 1999), *E. maidenii* seems likely to be able maintain this high stocking without mortality for some time.

Bole straightness was best for *E. maidenii* (7.0) and *E. globulus* showed least malformation. *Eucalyptus saligna*, and to some extent *E. globulus*, had signs of past broken tops which depressed straightness and malformation scores. The crown health of *E. maidenii* was good (6.3) but that of *E. globulus* was particularly bad. This species' future survival looks uncertain, based on its past mortality and present crown health.

Basic density of outerwood at breast height at age 11 years was high for *E. maidenii*, at 578 kg/m^3, somewhat lower for *E. globulus* (505 kg/m^3), and very low for *E. nitens* from southern NSW (estimated from Trial 1 at 412 kg/m^3) (Shelbourne unpubl. data). At age 8 years at Knudsen Road, the outerwood density of these species was respectively 530, 430, and 412 kg/m^3 (Shelbourne unpubl. data). Two provenances of *E. maidenii* (from Bolaro Mountain in the north, and Eden at the southern end of the range in NSW), two provenances of *E. globulus* (from Tasmania and Jeeralangs, Victoria), and three provenances of *E. nitens* from southern NSW were sampled.

Karaka Road

Four plots of seedlot N1 *E. nitens* from southern NSW and four plots of N2 *E. nitens* from Toorongo, Victoria, were assessed here, as a cross-check on their performance at Carnation Road (Table 6). This trial had been thinned to 50% stocking at age 2 years, like that at Carnation Road. There was somewhat higher recent mortality in the Toorongo seedlot than in that from NSW (14% *vs* 6%). The most noticeable difference was in crown health; the Toorongo provenance crown score was only 1.8, indicating most of the trees were now near death. The health score of the southern NSW seedlot was 4.0, which was appreciably lower than at Carnation Road. Dbh was slightly lower for the NSW seedlot and inner-plot basal area was 51 m^2/ha for the NSW and 39 m^2/ha for the Victoria provenance. Compared to Carnation Road, dbh of both provenances was much lower, stocking of the NSW seedlot was higher, and basal area was a little higher; however, the general health and current growth of the NSW provenance appeared worse at Karaka Road.

TABLE 5–Carnation Road Trial 2 species means and F tests

Species and origin	Crop trees (%)	Mortality (%)	Runts (%)	Basal forks (%)	Height (m)	Dbh (mm)	Basal area (m^2/ha)	Volume (m^3/ha)	Bole straightness (1–9)	Malformation (1–9)	Crown health (1–9)
E. globulus California, USA	60 a	33 b	8 a	0	21.7	212 b	27 ab	228 b	6.5 a	7.4 a	3.0 c
E. maidenii Waiohiki, Napier, NZ	80 a	14 ab	6 a	0	22.7	236 a	42 a	353 a	7.0 a	6.4 ab	6.3 a
E. grandis Sabie, S. Africa	61 a	21 ab	18 a	0	22.2	211 b	24 b	211 b	5.1 b	5.1 b	6.1 a
E. saligna Mixed	56 a	9 a	35 b	0	21.7	214 b	26 ab	244 ab	6.3 a	5.5 b	5.0 b
F tests for species	1.84	3.93*	16.32***	0	2.11	11.40**	13.55***	5.57*	12.67**	7.81**	93.30***

TABLE 6–Karaka Road provenance means and F tests

Species and origin	Crop trees	Early mortality and thinnings	Later mortality	Runts	Basal forks	Dbh (mm)	Basal area (m^2/ha) Whole	Basal area (m^2/ha) Inner	Bole straightness (1–9)	Malformation (1–5)	Crown health (1–9)
E. nitens N1 southern NSW	42 a	52 a	6 a	0	8 b	253 a	57 a	51 a	5.8 a	4.5 a	4.0 a
E. nitens N2 Toorongo, VIC	32 b	53 a	14 a	0	1 a	242 a	39 b	39 a	6.1 a	4.5 a	1.8 b
F tests for seedlot	11.37*	1.00	9.00	0	11.96*	5.42	54.59**	5.33	1.23	0.06	111.52**

Walker Road Trials 1 and 2

The results of these trials are best considered together, though the data from them had to be analysed separately. Results from Trial 1 are shown in Table 7, and from Trial 2 in Table 8. With only two replicates in Trial 1, its precision was low. The two trials together accommodated six seedlots of *E. nitens*, four of them native populations. These ranged from Barrington Tops, northern NSW, to central Victoria. *Eucalyptus globulus* was represented by southern Tasmanian and Victorian provenances, and *E. saligna* was represented in both trials as a Tairua, New Zealand, seed orchard seedlot.

Total mortality was high for seedlot NMIX (51%), a mix of eight Victorian provenances, and very high for *E. nitens* N32 from Glentunnel, New Zealand, which is a second-generation seedlot originating from central Victoria and presumed to be inbred. Mortality of this seedlot was under-estimated at 70%, as one whole plot of trees was dead or missing, and not analysed. NSW provenances of *E. nitens* generally showed lower mortality. *Eucalyptus saligna* had a high percentage of runts (27% and 39% in Trials 1 and 2 respectively) and did not show serious early or later mortality. Basal forking was not a problem with any seedlots in these trials.

In Trial 1, *E. nitens* from Barrington Tops had the highest basal area, though dbh was lower than that of NMIX, the mix of Victorian provenances. In the second trial, *E. nitens* from Nimmatabel in southern NSW had the highest dbh and basal area.

Bole straightness was generally acceptable for all species except *E. globulus* from southern Tasmania in Trial 1, which also suffered severe malformation. The Jeeralang, Victoria, provenance did not have the same problem in Trial 2.

Health score for *E. globulus* from Tasmania averaged 4.1 and this provenance looked very sick. Health of *E. globulus* from Victoria was much better (5.6). Health score of *E. nitens* central Victoria seedlots in Trial 1 and Trial 2 ranged from 4.0 to 4.8 whereas NSW seedlots ranged from 6.3 for Nimmatabel to 5.4 for Mt. Anembo (Tallaganda).

Basal area of the more vigorous seedlots was generally over-estimated in the whole plots *vs* the inner plots. The higher mortality in Victorian provenances of *E. nitens* tended to result in higher dbh at this age but the basal area of NSW provenances was generally higher than Victorian provenances, reflecting their lower mortality and better health.

Knudsen Road

Provenance group and species means from the Knudsen Road trial are shown in Table 4 (from Low & Shelbourne 1999) for *E. nitens* provenances from NSW and Victoria, *E. globulus, E. maidenii, E. grandis, E. saligna*, and *E. botryoides* for purposes of comparison. It was noticeable that the *E. nitens* provenances from NSW, aged 7 years, had healthier crowns (score 5.6) than the N1 (southern NSW) seedlot at the Carnation and Karaka Road trials, aged 11 years (score 5.0). Mean basal area for Victorian provenances (19 m^2) was half that of southern NSW provenances (40 m^2), though mean dbh was the same for both, reflecting the extremely high recent mortality there of Victorian provenances. Apart from this, this trial gives further confirmation of the ill-health of *E. globulus* and the good health of *E. maidenii*.

TABLE 7–Walker Road Trial 1 species and provenance means

Species and origin	Crop trees	Early mortality	Later mortality	Runts	Basal forks	Dbh (mm)	Basal area (m^2/ha) Whole	Basal area (m^2/ha) Inner	Bole straightness (1–9)	Malform-ation (1–5)	Crown health (1–9)
E. globulus G89, Cygnet, TAS	53a	12a	30a	3a	0a	226 ab	24 a	24 a	4.4 a	3.6 c	4.1 a
E. nitens N22, Barrington Tops, NSW	66a	17a	13a	4a	2a	223 ab	34 a	32 a	6.1 a	4.5 a	6.2 a
E. nitens N63, Mt Anembo, NSW	63a	20a	13a	5a	1a	213 b	30 a	28 a	6.3 a	4.8 a	5.4 a
E. nitens NMIX, Central VIC	38a	24a	27a	11a	0a	250 a	26 a	20 a	6.5 a	4.6 a	4.6 a
E. saligna S89, Tairua, NZ	54a	12a	7a	27a	0a	175 c	21 a	21 a	6.6 a	4.0 b	5.3 a
F tests for seedlot	0.71	0.90	2.15	6.1	1.22	22.93**	0.77	5.17	1.28	13.30*	5.24

TABLE 8–Walker Road Trial 2 species and provenance means and F tests

Species and origin	Crop trees	Early mortality	Later mortality	Runts	Basal forks	Dbh (mm)	Basal area (m^2/ha) Whole	Basal area (m^2/ha) Inner	Bole straightness (1–9)	Malform-ation (1–5)	Crown health (1–9)
E. globulus G31, Jeeralang, VIC	36 ab	41 ab	16 a	7 a	8 a	224 b	20 bc	20 ab	6.07 a	4.63 a	5.59 b
E. nitens N32, NZ, ex VIC	21 b	45 b	25 a	8 a	6 a	232 ab	13 c	12 b	6.49 a	4.80 a	4.04 d
E. nitens N33, Toorongo, VIC	48 a	38 ab	8 a	7 a	3 a	225 b	25 ab	24 a	6.41 a	4.68 a	4.82 c
E. nitens N34, NZ ex Nimmitabel, NSW	50 a	33 ab	9 a	8 a	6 a	245 a	32 a	26 a	6.07 b	4.77 a	6.27 a
E. saligna S31, Tairua, NZ	40 a	16 a	5 a	39 b	0 a	186 c	19 bc	19 ab	6.63 a	4.31 b	6.01 ab
F tests for seedlot	7.22**	3.60*	1.06	43.20***	2.14	11.68***	13.55***	3.17*	2.30	6.43**	11.75***

IMPLICATIONS AND CONCLUSIONS

Although *E. fastigata* was assessed only at Carnation Road, it grew well at Karaka Road and excelled all other species in these trials for adaptation, health, and volume growth. The Oakura, New Zealand, seedlot grew particularly well, with a MAI of 60 m^3/ha. However, form of these seedlots was marred by frequent basal forking and some tendency to fork higher up the stem, a common drawback of this species. Certain seedlots appear to be straighter and unforked—for instance, a particular South African seedlot planted as a filler in an *E. nitens* trial at Walnut Road, Kinleith, and in a 40-ha stand at Tolaga Bay (R.M.McConnochie pers. comm.), and progenies from this South African population are well represented in the *E. fastigata* breeding programme. *Eucalyptus regnans* suffered from early mortality (P.Smale unpubl. data) caused by *Phytopthora* spp., but volume growth was only a little less than for *E. fastigata* (average MAI 50 m^3/ha), and crown health appeared good. However, this species is not generally well-regarded because of poor health due to the Barron Road Syndrome (M.Dick pers. comm.).

Eucalyptus nitens showed generally poor crown health and high mortality at Carnation Road and even worse crown health, especially in Victorian provenances, at Karaka Road. Although the southern NSW seedlot appeared more healthy than the central Victorian, the current growth rate appeared depressed, the volume growth was lower than *E. fastigata* and *E. regnans* (MAI 40 m^3/ha), and the prospects for continued good growth look poor.

At the Walker Road trial, which was 2 years younger, the Victorian seedlots of *E. nitens* showed poorer health, more mortality, and slower growth than the provenances from northern and southern NSW. At Knudsen Road (Low & Shelbourne 1999) at age 7 years (and presently at age 8), *E. nitens* of Victorian provenances showed acute mortality and health problems but the NSW provenances from northern and southern populations were still healthy in the crown and much less subject to mortality. This species is generally ill-adapted to the warm climate of Northland, which has rainfall throughout the year and clay soils, coming as it does from much higher altitudes between latitude 37° and 31°S; decline with age is just a matter of time. Breast-height outerwood density of *E. nitens* from southern NSW, which is important in kraft pulping and also for solid wood products, is particularly low in Northland, i.e., 412 kg/m^3 at age 11 at Carnation Road, and the same at age 8 at Knudsen Road (Shelbourne unpubl. data).

Eucalyptus saligna was the original species of choice for Northland. It has become afflicted by two insect pests—the gall wasp *Ophelimus* spp., and the brown lace lerp *Cardiospina fiscella*, which is a sap sucker. The latter has probably not reached these trials yet in its northern migration but it is causing complete defoliation of *E. saligna* as far north as Whangarei (T.Withers pers. comm.). However, a new parasitic wasp, *Psyllaephagus gemitis*, has been found recently, parasitising populations of *C. fiscella* in Northland and Auckland (Withers & Bain 2000). Also, possums and/or wind appear to have caused past top breakage, as is evidenced by stem bends and forking. In addition to these problems, this species at these ages showed a high proportion of "runts", poorly-grown subdominants, as well as low basal area and volume per hectare (average MAI 28 m^3/ha at Carnation Road), which disadvantages it as a short-rotation pulpwood species. As well, its sawing properties are marred by severe growth stresses (Haslett 1990). As a consequence of all these problems, it can no longer be considered a viable species option for Northland. Much the same can be said about *E. grandis*, a related and less well-adapted species with a natural distribution centred on summer rainfall, subtropical latitudes.

Eucalyptus globulus showed similar health problems to the Victorian provenances of *E. nitens* at both Carnation Road and Walker Road. However, the Jeeralang, Victoria, provenance at Walker Road had better crown health than the Tasmanian provenance. Volume growth of *E. globulus* was substantially less than the best provenances of *E. nitens*, especially in Trial 2 where the Victorian provenance was well replicated. Thus, *E. globulus* of either Tasmanian or Victorian provenance is evidently less well adapted to these sites than NSW provenances of *E. nitens* whose long-term health and survival prospects are still poor. At Knudsen Road both Tasmanian and Victorian provenances of *E. globulus* showed half the basal area of NSW *E. nitens* and have much poorer crown health. *E. globulus* would be the species of choice from a kraft pulping standpoint on account of its excellent fibre properties and relatively high wood density compared with *E. nitens* and *E. fastigata*, but it is evidently poorly adapted to Northland. *Eucalyptus pseudoglobulus*, a closely related taxon from eastern Victoria, (see Fig. 1), has not been tried in Northland but at Omataroa, in the coastal Bay of Plenty, (S.Concheyro *et al.*, unpubl.) it has performed better than *E. globulus* provenances from Victoria, in growth at age 4 and in health at age five (T. Withers and M.O. Kimberley, unpubl.). As a species with a Victorian distribution intermediate between *E. globulus* and *E. maidenii*, given the results of the Northland trials, *E. pseudoglobulus* would be worth trial planting.

Eucalyptus maidenii, another member of the *E. globulus* species complex (also known as *E. globulus* ssp. *maidenii*), showed much better crown health than *E. globulus* and *E. nitens* at Carnation Road, and had similar health to the best NSW provenance of *E. nitens* at Knudsen Road (Low & Shelbourne 1999). However, at age 7 at Knudsen Road its basal area was only 70% of that of the best NSW *E. nitens*. In Trial 2 at Carnation Road its volume growth at 43 m^3/ha/year was also less, apparently, than that of *E. fastigata* and *E. regnans* in Trial 1 at over 50 m^3/ha/year. How much of this difference was due to different site conditions between the two trials is uncertain (the same *E. saligna* material was 3 m shorter in Trial 2 than in Trial 1 and its volume per hectare was 29% less). Outerwood density of *E. maidenii* of 578 kg/m^3 *vs* 412 kg/m^3 for *E. nitens*, its ability to carry high stockings without mortality, its good form and good health all stand in its favour.

The good health of the northern and southern NSW provenances of *E. nitens*, of *E. fastigata*, and *E. maidenii* (as well the good adaptation of *E. saligna*, apart from insect attack), all from NSW, is noteworthy. This suggests that eucalypt species from south-eastern Australia that come from areas where there is some rainfall during summer or even a summer rainfall peak (as opposed to strongly winter rainfall) may be better adapted to Northland, coastal Bay of Plenty, and possibly other North Island climates. The prevalence of infection and defoliation by *Mycosphaerella* spp. and by *Kirramyces eucalypti* of young *E. nitens* in the Bay of Plenty, especially of central Victorian provenances, which is currently causing concern, is one example. Provenances of *E. nitens* from NSW have been less affected by *Mycosphaerella* spp. in summer rainfall climates in South Africa (Purnell & Lundquist 1986), and in Victoria *E. maidenii* and to a lesser extent Victorian provenances of *E. globulus* have been shown to be less affected by *Mycosphaerella* spp. than Tasmanian provenances (Carnegie *et al.* 1994). The climatic domains characterised for *E. fastigata* in NSW contrast with those for *E. nitens* and *E. regnans* in central Victoria in showing more rainfall in the summer months (Lindenmayer *et al.* 1996).

These trials have provided valuable experience with replicated large plots for comparing species and provenances, and some incidental lessons can be learnt from this about plot size and tree numbers per plot. Experience with permanent sample plots has shown that minimum numbers of between 10 and 15 trees per plot at final stocking are needed in estimating basal area and volume per hectare. Testing different species and different provenances requires replicated trial designs that can handle long-term inter-plot competition effects. One or two border rows around each measurement plot are needed, depending on the disparity in growth between different taxa. In these trials, plot size at Carnation Road Trial 1 was 0.025 ha, 16 × 16 m with 64 trees at a stocking of 2500 stems/ha; at Walker Road plots were 0.045 ha, 16 × 28 m, with 64 trees at about 1430 stems/ha; and at Knudsen Road plots were 0.019 ha, 14 × 13 m, with 49 trees at 2631 stems/ha.

If a final stocking of 800 stems/ha up to age 15 years is assumed to be suitable for trials of pulping species, inner measurement plots, with the plot size and spacing used, would contain 12 trees at Carnation Road Trial 1, 20 at the Walker Road trials, and eight at Knudsen Road. At Walker Road, with a whole-plot size of 0.045 ha, there were from 17 to 24 measurable crop trees per inner plot.

A plot of 0.044 ha, 21 × 21 m, with 49 trees (inner plot 25 trees) planted at 3 × 3 m or 1111 stems/ha, with 800 stems/ha surviving (18 trees in the inner plot), would be a suitable design for such trials. A whole plot with a 2-row surround of 81 trees would be a safer alternative but would require 66% more land. If trials are required to be thinned for eventual production of sawlogs on longer rotations (for example, to 300 stems/ha), a plot of 0.090 ha, 30 × 30 m, with 100 trees (inner plot 64 trees), planted at 3 × 3 m spacing (1111 stems/ha) would be necessary to leave 17 trees in the inner plot at final stocking. Trials with large plots can accommodate relatively few entries with a few replications without being excessively large and costly to establish and assess. Unfortunately, tests of different species require continuation nearly to rotation age under stand conditions.

ACKNOWLEDGMENTS

The foresight of New Zealand Forest Products Forests Ltd (now Carter Holt Harvey) in initiating these well-designed trials must be commended; the lack of long-term species and provenances trials in many other parts of New Zealand hampers successful planting of alternative species. The help of R.Cameron in the field assessment and Eva Moke with wood density determinations, and the co-operation of CHH Forests Ltd are gratefully acknowledged.

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