FAMILY TESTS AS A BASIS FOR THE GENETIC IMPROVEMENT OF EUCALYPTUS NITENS IN NEW ZEALAND

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(Received for publication 18 January 1988; revision 3 October 1988)

ABSTRACT

Vigorous and healthy growth (16-m heights) was shown by 8-year-old **Eucalyptus nitens** (Deane & Maiden) Maiden families in New Zealand trials Central Victorian families were 10–15% greater in diameter growth and 35–50% better in tree form scores than seedlots from eastern Victoria (Errinundra) and southern New South Wales. There were no large or consistent differences among the three provenances of central Victoria – Macalister, Toorongo, or Rubicon. The large variation between populations within the Toorongo provenance, showing the Mt Erica population top ranked for diameter growth and the Upper Thomson River population bottom ranked, supports the theory of introgression from the Errinundra variety.

Multiple-trait index selection across sites was used to choose the best 20 central Victorian half-sib families. Selection of these families should give gains of 7.5% for diameter, which equates to a 19% volume gain, over unselected central Victorian families. Predicted gains in form score are 8% for these selected families. Genetic variability in resistance to wind damage was demonstrated and this characteristic was also used in the selection of half-sib families. Half-sib family selection can be utilised for seed production gains and there are methods of advancing the population in open-pollinated families.

Keywords: provenance selection; family selection; index selection; **Eucalyptus nitens.**

INTRODUCTION

Eucalyptus nitens is a fast-growing species of the southern blue gum group of eucalypts though its timber properties are regarded as being similar to those of the better quality ash group (Hall *et al.* 1970; Turnbull & Pryor 1978; Forest Research Institute 1984). The species occurs naturally in four widely separated regions of south-eastern Australia – central Victoria, including the Toorongo Plateau and adjacent areas around the Baw Baw Ranges, and the Rubicon and Macalister areas; the Errinundra Plateau of eastern Victoria; southern New South Wales; and locally in northern New South Wales (Pederick 1979).

Pederick (1979) detected considerable variation both between and within provenances in progeny trials replicated at two sites in Victoria. The Errinundra provenance was shown to be highly distinct, with comparatively slow growth rates, early development of mature foliage, marginal glands on mature leaves, and fluorescent polyphenolic substances in the leaves. Pederick suggested that the Errinundra provenance was sufficiently different from the other population groups to be designated as a taxonomic variety (var. *errinundra*).

The provenances from the central Victorian highlands, with persistent, glaucous, juvenile leaves, were considered the most desirable selections because of better growth rate, straightness, and branch habit (Pederick 1979). In addition, the more persistent juvenile foliage of these provenances appears to confer a degree of frost resistance (Nixon 1977; Tibbits & Reid 1987). The Toorongo provenance from central Victoria was unusual in that it contained some of the fastest-growing populations available (Mt Erica and Mt St Gwinear) but there were also local populations that had the slow growth and less persistent juvenile foliage characteristics of the Errinundra provenance. Pederick (1979) hypothesised that gene flow from the Errinundran variety has occurred in some of the Toorongo populations.

The enthusiasm for *E. nitens* in New Zealand has been patchy and cyclical. Early introductions were made by the New Zealand Forest Service from Toorongo and Errinundra, and the spectacular early growth of the Toorongo seedlot resulted in some enthusiasm for this species (Franklin 1980). NZ Forest Products Ltd has experimented with *E. nitens* as a fast-growing species for short-fibre pulps (Lembke 1977) and interest is currently being expressed in *E. nitens* for firewood and energy production (Tombleson 1986). However, in spite of its vigorous growth habit, good form characteristics, and cold-hardiness, *E. nitens* has been in disfavour in New Zealand because of its susceptibility to the defoliating Eucalyptus tortoise beetle *Paropsis charybdis* (Stål) (Wilcox 1980). It is currently thought that *E. nitens* is possibly best suited to the South Island and cold inland parts of the North Island where *P. charybdis* may be less of a hazard, and the advantages that *E. nitens* displays in cold wet conditions outweigh its difficulties with defoliating insects. Early reports from South Island provenance trials indicate the over-all superiority of central Victorian origins for growth rate and fine branching (Franklin 1980).

Tree improvement for *E. nitens* in New Zealand, guided by Dr Leon Pederick's seed source recommendations, is being concentrated on the selection of the best open-pollinated progenies from 80 families of the three central Victorian provenances (Rubicon, Toorongo, and Macalister). Improved growth and form are considered valuable objectives for the improvement of *E. nitens* in New Zealand. This paper reports results of assessments (between ages 6 and 8 years) from the family/provenance tests at Kaingaroa Forest, Rotoaira Forest, and Longwood Forest in Southland, and suggests ways of achieving genetic improvement.

MATERIALS AND METHODS

Details of the families studied are shown in Table 1. In addition to the central Victorian families there is a commercial collection (Blue Range, Rubicon), an Errinundra seedlot (Bendoc), a northern New South Wales seedlot (Barrington Tops), and a southern New South Wales seedlot (Tallaganda). The seed was supplied by Dr Leon

Pederick of the Department of Conservation, Forests and Lands, Victoria, Dr Ken Shepherd of the Australian National University, Canberra, and Mr John Doran of the CSIRO Division of Forestry and Forest Products Research, Canberra.

Planting and Design: Planting stock type, time of planting, number of replicates, and the number of families planted varied from site to site but they were all planted

TABLE 1–Origins of *Eucalyptus nitens* families in the New Zealand provenance/progeny trials

Origin	Lat. (S)	Long. (E)	Alt. (m)	No. of families
RUBICON : CENTRAL VICTORIA				
Mt Torbreck	37°22'	145°55'	729	2
Royston Range	37°25'	145°45'	950	1
Toolangi	37°32'	145°34'	610	5
Cathedral Range	37°20'	145°47'	1036	4
Blue Range Road	36°23'	145°47'	1000	7
Federation Range	37°25'	145°55'	1100	2
Mount Victoria	37°40'	145°40'	1127	1
Tweed Spur	–	–	975	1
Snob's Creek	–	–	930	1
Barnewall Plain	–	–	1190	1
Bullfight Creek	–	–	1020	1
Royston Road	–	–	1000	1
Royston Road	–	–	950	1
TOORONGO : CENTRAL VICTORIA				
Toorongo Plateau	37°36'	146°10'	1066	4
Toorongo Plateau	37°50'	146°13'	854	2
Toorongo Plateau	–	–	880	1
Mount Horsfall, Toorongo Plateau	37°48'	146°00'	701	5
Mount Erica	37°50'	146°20'	1067	2
Mount Erica	37°54'	146°20'	1070	1
Mount Erica	–	–	1060	2
Mount St Gwinear	37°50'	146°21'	1175	10
Mount St Gwinear	–	–	1150	1
Starling Hill, Powelltown	37°48'	145°50'	762	2
Link Road, Noojee	37°48'	146°04'	960	3
Upper Thomson	–	–	1050	2
Penny's Saddle	–	–	810	1
Mississippi, Powelltown	–	–	820	2
MACALISTER : CENTRAL VICTORIA				
Heyfield	37°26'	146°21'	1000	1
Mount Useful	37°40'	146°30'	1295	3
Connor's Plain	37°32'	146°28'	1310	4
Mount Skene	–	–	1160	2
Mount Wellington	–	–	1270	2
Connor's Plain	–	–	1250	2
OTHER SEEDLOTS				
Commercial collection, Rubicon, Victoria	–	–	–	–
Bendoc, Errinundra				1
Barrington Tops, NSW				1
Tallaganda, NSW				1

in a single-tree plot randomised complete block design. Seedlots were randomly assigned to two sets of 42 seedlots for convenience of handling and assessment. Sites reported in this study were at Rotoaira Forest and Kaingaroa Forest in the Central North Island and at Longwood Forest in Southland where only one set was planted. Details of the sites and of the handling of the material at the individual sites are given in Table 2.

Assessment: Details of the assessments made at each of the trials are reported in Table 2. A final assessment of diameter, form, and fruitfulness was recorded prior to marking for thinning – approx. mean crop height of 16 m. This paper reports details of this assessment at Rotoaira (8 years), Kaingaroa (6 years), and Longwood (8 years). The Rotoaira site had suffered damage from a windstorm 2 months prior to assessment, and damage was recorded as either windthrow or stem breakage. Seed production was recorded in order to make second-generation seed collections. Heights were assessed separately on a sample of 50 trees from each of the three sites in order to obtain an effective crop height and standing volume.

TABLE 2–Details of planting and experimental design, and details of assessments for individual sites of the *E. nitens* provenance/progeny trial

Location	Month and year of planting, stock, and initial spacing	Number of sets planted and number of replications	Assessment time and traits
Rotoaira lat. 39°00'S alt. 700 m	11/78, peat pots 3 months from sowing, 3.43 × 3 m.	Two sets of 42 seedlots, 36 replicates.	9/86: diameter (cm) form (1–9)*, fruitfulness (0–3)†, windfirmness (0,1).
Kaingaroa lat. 38°30'S alt. 230 m	7/79, bare-rooted stock pricked out 11/78, 3 × 3 m.	Two sets of 42 seedlots, 30 replicates.	12/85: diameter, form.
Longwood, Southland lat. 46°15'S alt. 100 m	11/78, peat pots 3 months from sowing, 3.5 × 3.5 m.	One set of 42 seedlots, 27 replicates.	5/86: diameter, form, fruitfulness.

* 1 bad → 9 good
† 0 no seed → 3 abundant seed

Statistical Analysis

Family means were calculated for each site separately and over all sites in order to rank family performances. Arithmetic means using individual tree values were used. Means were also calculated for the provenance groups.

Analysis of variance was conducted in order to test for the significance of genetic sources of variation and to estimate variances and covariances as an aid to using selection for the improvement of *E. nitens*. The analyses of families were done for each site separately and over all sites. Family components of covariance among traits were calculated by using the variance component model on the sum of the value for the pair of traits in question and solving for the covariance term (Kempthorne 1957 p. 264).

At individual sites, the model (assumed to be fully random) was:

$$Y_{ij} = \mu + r_i + f_j + e_{ij} \quad (1)$$

where Y_{ij} = the observation of the tree in the ith replicate and the jth family
μ = the general mean
r_i = the effect of the ith replicate
f_j = the effect of the jth family
e_{ij} = random error associated with the ijth tree

On the individual sites, sets were combined and ignored in the model after confirmation that there were no significant effects caused by the random partitioning into sets.

The model for the analysis over all sites was:

$$Y_{ijk} = \mu + s_i + r_{j(i)} + sf_{ik} + e_{ijk} \quad (2)$$

where Y_{ijk} = the observation of the tree in the kth family and the jth replication at the ith site
μ = the general mean
s_i = the effect of the ith site
$r_{j(i)}$ = the effect of the jth replicate within the ith site
f_k = the effect of the kth family
sf_{ik} = the effect of the interaction between the ith site and the kth family
e_{ijk} = random error associated with the ijkth tree

On combined sites, as the number of sets were not used on all sites (Table 2) analyses were done on a set-by-set basis – set one using all three sites, set two only Kaingaroa and Rotoaira.

Genetic Analysis

The phenotypic variance of family means $\sigma^2_{\bar{f}}$ was estimated at each site separately as:

$$\hat{\sigma}^2_{\bar{f}} = \hat{\sigma}^2_f + \frac{\hat{\sigma}^2_e}{t} \quad (3)$$

where σ^2_f and σ^2_e are the variance components of family and error, respectively, as estimated in the model given by Equation 1, and t is the mean number of trees per family at each site.

The phenotypic variance of family means was estimated over all sites as:

$$\hat{\sigma}^2_{\bar{f}} = \hat{\sigma}^2_f + \frac{k_{sf}}{k_f}\hat{\sigma}^2_{sf} + \frac{\hat{\sigma}^2_e}{k_f} \quad (4)$$

where σ^2_{sf} is the variance component of family × site interaction, and σ^2_f, σ^2_{sf}, and σ^2_e are as specified in the model given by Equation 2, and k_{sf} and k_f are the coefficients of the variance components of this model.

Variance estimates used as genetic parameters in predicting gains can also be expressed as coefficients of variation:

$$\hat{CV}_{\bar{f}} = \frac{\hat{\sigma}_{\bar{f}}}{\bar{x}} \times 100\%$$

where $\bar{x}$ is the mean of the half-sib families. Expressed as a percentage of the mean like this, variability at each site can be compared, with the effect of removing the differences in over-all scale, and gains are readily expressed as percentage gains.

The repeatability of family means at each site separately and over both sites was then calculated as:

$$\hat{h}^2_{\bar{f}} = \frac{\hat{\sigma}^2_f}{\hat{\sigma}^2_{\bar{f}}} \quad (5)$$

Several linear correlation coefficients were calculated. A phenotypic correlation of family means, r_f was calculated at each site separately and over all sites. Genetic correlations r_g were calculated within sites using the family components of variance and covariance. Genetic correlations between sites were calculated using the mean cross-products from the family means at each site divided by the square root of the product of the within-site genetic variances (Burdon 1977). Correlated response to selection was calculated as per Falconer (1982).

Selection for Genetic Improvement

The objectives of genetic selection for *E. nitens* are to provide an improved seed source from central Victorian families for New Zealand conditions and to carry on a further cycle for recurrent selection. We outline here the potential results of half-sib family selection. Expected gain from half-sib family selection is simply expressed as:

$$\Delta G = ih^2_{\bar{f}} \times CV_{\bar{f}}$$

where i is the selection intensity, or as:

$$\Delta G = h^2_{\bar{f}} \times S_{\bar{f}} \quad (6)$$

where $S_{\bar{f}}$ is the selection differential of half-sib families.

Multiple trait index selection (MTIS) was investigated at Rotoaira for diameter and form in conjunction with independent culling for windfirmness. Multiple-trait index selection for diameter and form was also carried out across all sites on a set-by-set basis – Rotoaira and Kaingaroa for Set 2 and for Set 1 at all three sites. Index selection was for half-sib family selection using the models demonstrated by Lin (1978).

Families were ranked by their index values from:

$$I_j = \Sigma_p b_p X_j^p \quad (7)$$

where I_j = index value of the jth family
b_p = weighting factor for the pth trait
X_j^p = the phenotypic value of the pth trait for the jth family

The b's are found from:

$$\mathbf{b} = \mathbf{P}^{-1}\mathbf{Ga} \quad (8)$$

where **b** = the vector of index weights
P = the phenotypic variance-covariance matrix of family means
G = the matrix of family variances and covariances
a = the vector of economic weights.

The expected gain in the genetic value of each trait for index selection has been given by Lin (1978):

$$\Delta G_i = i(b' G_i) / \hat{\sigma}_I \qquad (9)$$

where i = the selection intensity

G_i = row vector of genetic covariances between the ith trait and each component trait in the index

σ_I = the standard deviation of the index

$\sigma_I^2 = \mathbf{b'\,P\,b}$

Selection across all sites was carried out on a set-by-set basis using the site-by-site covariances for index selection (Burdon 1979).

RESULTS AND DISCUSSION

General Growth of the Species

Eight-year-old dominant mean height of the crop at Rotoaira and Longwood was 16 m. Volume per tree ranged from 0.15 to 0.20 m^3 on these two sites. The heights and volumes of the *E. nitens* at Rotoaira were noticeably better than a similarly aged adjoining plantation of *Pinus radiata* D. Don. *Eucalyptus nitens* thus shows impressive volume growth in cool temperate conditions.

Provenance Differences

Mean values for diameter and form by provenances and for some of the populations are given in Table 3. The central Victorian provenances were the most promising seed sources for New Zealand conditions. The Errinundra seedlot was bottom-ranked and the two New South Wales seedlots were in the bottom 15 percentile for diameter (Table 3). The diameter mean of the central Victorian families was 10% and 15% higher than the New South Wales and Errinundra lots respectively.

There was no consistent indication as to which was the best of the central Victorian provenances. The Toorongo provenance was top ranked for both diameter and form at Rotoaira and Longwood ($p < 0.05$, SNK test in both places) but this provenance was bottom-ranked among the central Victorian provenances at Kaingaroa ($p < 0.05$ for diameter but NS for form). There was, however, considerable variability within this provenance group. Certain of the Toorongo populations (Mt Erica, Mt St Gwinear, Mt Horsfall) were consistently top-ranked while others (Upper Thomson River) were bottom ranked and comparable in growth to the Errinundra provenance (Table 3). Pederick (1979) also found this contrast in the Victorian trials, where the Mt Erica source, as in our trials, was the most superior population for growth rate; but Pederick found that populations to the south-west of the Baw Baw Ranges, especially Christmas Creek, Tanjil Bren, and to a lesser extent Mt Toorongo, were closer in growth rate to the Errinundra variety. He hypothesised that gene flow from the Errinundra variety was present in some populations of the Toorongo provenance. In our results the Upper Thomson River families (Toorongo) were close in performance to the bottom-ranked Errinundra seed source. Although Pederick did not find this poor performance in his sample of Upper Thomson River families, our data demonstrate the variability in the

TABLE 3–Provenance group means

Origin	Over-all mean			Rotoaira			Kaingaroa		Longwood‡	
	Dia. (cm)	Form (1–9)	Surv.* (%)	Dia. (cm)	Form (1–9)	Wind† (%)	Dia. (cm)	Form (1–9)	Dia. (cm)	Form (1–9)
Plantation mean	16.0	6.8	81	16.9	6.9	25	14.3	6.7	17.1	7.2
All central Victorian families	16.0	6.9	82	17.0	6.9	26	14.4	6.8	17.1	7.2
Macalister families	16.0	6.8	83	17.0	6.5	25	14.7	6.9	16.2	6.9
Rubicon families	15.7	6.7	83	16.4	6.8	29	14.5	6.6	16.8	7.0
Toorongo families	16.2	7.1	79	17.5	7.2	23	14.1	6.8	17.9	7.4
Upper Thomson River families, Toorongo	11.7	5.4	40	12.8	6.5	8	10.9	4.6	–	–
Mt Erica families, Toorongo	17.4	7.4	88	18.6	7.7	22	15.5	7.1	18.6	7.5
Family #114, Mt Erica, Toorongo	18.7	7.3	87	19.7	7.3	11	16.7	7.2	19.9	7.5
Errinundra, Victoria	11.3	5.8	21	13.2	6.7	0	9.4	4.9	–	–
Tallaganda, NSW	14.4	3.9	92	15.4	3.9	9	13.1	4.0	–	–
Barrington Tops, NSW	14.8	5.6	83	15.7	5.3	7	13.8	5.8	–	–
Commercial collection	16.1	7.2	85	17.0	6.9	34	14.8	6.6	16.5	7.8

* Surv. refers to percentage of surviving stems prior to Rotoaira windstorm.
† Wind refers to percentage windblow.
‡ Longwood has only one set.

Toorongo provenance and suggest that the incursion of the Errinundra genes into the Toorongo populations may be fairly extensive. This indicates care must be taken in seed source selections from the Toorongo provenance.

The central Victorian provenances were best also for form in comparison to the Errinundra and New South Wales seedlots. The central Victorian families scored 35% better for form. The Tallaganda, New South Wales, seed source was particularly and consistently poor in form (Table 3). The slow growth of the Errinundra and Upper Thomson River seedlots was reflected in poor survival for this assessment (<50%; Table 3).

There was also a good deal of variation between families within the central Victorian provenances. This is shown particularly well by the high performance of outstanding families such as #114 Mt Erica (Table 3). These differences between families can be used as a basis for selection for the improvement of *E. nitens* within the central Victorian provenances.

Selection for Growth, Form, and Windfirmness at Rotoaira

Analysis of variance and covariance for diameter and form on combined sets of the central Victorian families at Rotoaira are presented in Table 4 (Equation 1).

TABLE 4–Analysis of variance and covariance on combined sets of central Victorian families at Rotoaira

Source	Diameter			Form	
	df	Mean squares	F ratio	Mean squares	F ratio
Rep	35	40.3100	4.73	7.3549	2.35
Family	78	42.7761	5.02	14.0010	4.47
Error	1655	8.5227		3.1348	
σ^2_f		1.5417		0.4891	
$\sigma^2_{\bar{f}}$		1.9253		0.6303	
$h^2_{\bar{f}}$		0.80		0.78	
$\bar{X}$		17.06		6.92	
$CV_{\bar{f}}$		8.13		11.48	
$\Delta G_1 = h^2_{\bar{f}} \times CV_{\bar{f}}$		6.5%		8.9%	
$\Delta G_2 = h^2_{\bar{f}} \times S_{\bar{f}}$		5.9%		10.0%	
$\Delta G_3 = b' G_i/\sigma_I$		6.5%		7.5%	
$r_{\bar{f}}$			0.54		
r_g			0.65		
CR_y			6.0%		

ΔG_1 Expected gain as a percentage per unit of selection intensity.

ΔG_2 Percentage expected gain using selection differentials ($S_{\bar{f}}$) at i = 1 or 30:80 of top selected families.

ΔG_3 Expected gains using MTIS at 2:1 economic weighting of diameter to form.

CR_y Correlated response of trait Y (form) selecting trait X (dia.) = $h_x h_y r_{\bar{f}} CV_f$ (Falconer 1982) given as a percentage gain per unit of selection intensity.

Significant family differences exist for both traits. Expected response to selection for diameter was over 6% per unit of selection intensity (i) (i = 1.0 at a selection intensity of 30 : 80 and this level of selection intensity will be used unless specific selection intensities are mentioned). Selection for form was also profitable with expected gains of 9%. Correlation of half-sib family means between diameter and form was large and significant (r = 0.53; $p < 0.001$). Genetic correlation was 0.65 and correlated response for form by selecting for diameter on its own was 6%. With this strong positive genetic correlation the additional effectiveness of using multiple-trait index selection (MTIS) was minor but still helpful. MTIS is for the aggregate breeding value, with each trait being weighted by its associated economic value. In this calculation the economic values were chosen empirically to maximise response for both traits. At a 2 : 1 economic weighting ratio of diameter to form, expected response to diameter could be kept close to maximum and expected response to form was 7.5%. This extra 1.5% gain for form in using MTIS over indirect selection for diameter was similarly shown in the selection differentials for the 30-family selection rate. Selection for diameter on its own gave S_{diam} = 1.25 cm or 7.3% and S_{form} = 0.44 or 6.3%, on the 2:1 index S_{diam} = 1.20 cm or 7.0% and S_{form} = 0.66 or 9.5%; thus 3.2% gain in form would more than compensate for a 0.3% loss in diameter.

Information for windfirmness was gathered on a half-sib family basis. Mean incidence of windblow in the central Victorian families was 25%. Families varied considerably and half-sib family windblows ranged from 0 to 19 trees (originally 36 trees per family). The differences between families were significant ($p < 0.001$) upon performance of a Chi-square test. Families ranged in number of snapped trees from zero to five, all snapping occurring at major forking malformations in the stem. There was a slight positive but non-significant ($p > 0.10$) association between family windblow and mean diameter (r = 0.11). Thus larger diameter families were no more inclined to blow over than smaller families. Family-mean correlation between this windblow incidence and a previous one (1982) was 0.34.

Selection Across Combined Sites

Variances and family repeatabilities from the combined sites analysis (Equation 2) are presented in Table 5. Significant family differences and site × family interactions were present for both diameter and form. The interaction variance was especially noticeable for diameter where it was 70% of the family variance component. A table of

TABLE 5–Variances and family repeatabilities from combined sites analysis of variance

Trait	Diameter	Form
σ^2_f	0.76***	0.33***
σ^2_{sf}	0.54***	0.07*
$\sigma^2_{\bar{f}}$	1.15***	0.42***
$h^2_{\bar{f}}$	0.66***	0.79***

Significance of sources of variation
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

genetic and phenotypic correlations is presented in Table 6. One of the causes of the large interaction variance for diameter were the poor correlations, i.e., different ranks, between the Kaingaroa and Longwood sites ($r_f = 0.19$; $p > 0.10$; Table 6). Unfortunately, only Set 1 families were available for this correlation. This set also produced non-significant ($r_f = 0.24$; $p > 0.10$) correlations between the Rotoaira and Kaingaroa sites, but when combined with the Set 2 families the diameter correlations were strong and significant ($r_f = 0.57$; $p < 0.001$). This suggests that the Set 1 families were more interactive than the population in general and the poor correlations reflect the results of sampling and poor estimations associated with small sample sizes rather than any fixed site effects. However, it is of interest to note that the Set 1 families planted at Golden Downs, Nelson (D. A. Franklin, unpubl. data) had a high, significant correlation with the Kaingaroa Set 1 families ($r_f = 0.49$), but non-significant correlation with the Longwood and Rotoaira Set 1 families.

Selections across sites were made using index selection (Equations 7 and 8). The variances and selection parameters needed for index selection are shown in Table 7. Expected gain by selecting across sites (ΔG_3) averaged around 6% per standard deviation unit of selection intensity for diameter and form. Twenty of the best families were chosen with this index with some independent culling for windfirmness. Mt Erica, Mt St Gwinear, and Mt Horsfall families were highly represented in this select group. It was apparent from the high incidence of these sources in selected families, that seed source selection from within the central Victorian families was an important factor in this half-sib family improvement. These predicted gains in diameter translate into volume increases for half-sib family index selection of the order of 19% for these top 20 families over unselected central Victorian families. These top 20 families have predicted gains in form score of 8%.

TABLE 6–Genetic (above diagonal) and phenotypic (below diagonal) correlations between sites for diameter and form, with significance levels of family means correlations shown alongside phenotypic correlations

	Rotoaira (8 yr)	Kaingaroa (6 yr)	Longwood (8 yr)
		Diameter	
Rotoaira		0.74	0.74
Kaingaroa	0.57***		0.30
Longwood	0.46**	0.19 NS	
		Form	
Rotoaira		0.93	0.79
Kaingaroa	0.70***		0.62
Longwood	0.53**	0.38*	

NS Non-significant p>0.05
* p<0.05
** p<0.01
*** p<0.001

CONCLUSIONS AND RECOMMENDATIONS

These trials showed good vigorous growth for this species. Central Victorian families from the Rubicon, Toorongo, and Macalister provenances were far superior

TABLE 7–Selection parameters for selection across sites

Selection parameter	Rotoaira		Kaingaroa		Longwood	
	Dia.	Form	Dia.	Form	Dia.	Form
$\hat{\sigma}^2_f$	1.608	0.4808	0.9768	0.3892	1.281	0.3038
$\hat{\sigma}^2_{\bar{f}}$	1.992	0.6212	1.330	0.5282	2.254	0.4736
$\hat{h}^2_{\bar{f}}$	0.80	0.66	0.73	0.74	0.57	0.64
$\bar{X}$	17.07	6.9	14.27	6.7	17.05	7.1
$\hat{CV}_{\bar{f}}$	8.27	11.37	8.08	10.84	8.80	9.65
$\Delta G_1 = \hat{h}^2_{\bar{f}} \times \hat{CV}_{\bar{f}}$	6.68	8.80	5.93	8.00	5.00	6.19
$\Delta G_3 = \hat{b}' \hat{G}_i / \hat{\sigma}_I$	6.59	7.46	4.70	6.96	5.52	4.04

ΔG_1 = Expected gain per selection intensity unit of half-sib selection on each site selected directly.
ΔG_3 = Expected gain per selection intensity unit of half-sib index selection across sites.

in both growth rate and form characteristics to seedlots from the other provenances of the species range – Errinundra, Victoria, and provenances from northern and southern New South Wales. The superior growth rate of central Victorian provenances was also demonstrated in trials in Victoria (Pederick 1979) and the West Coast of the South Island (Franklin 1980). The central Victorian seed source thus should provide the basis for the genetic improvement of this species in New Zealand and provide the material from which any future imports should be made. Some of the populations from the Toorongo provenance, such as Mt Erica, Mt St Gwinear, and Mt Horsfall, were particularly good. But care should be taken with seedlots selected from this provenance as there is evidence of introgression from the Errinundra variety (Pederick 1979). Sampling should avoid populations south-west of the Baw Baw Ranges including Christmas Creek and Tanjil Bren, and any sampling from populations in the Mt Toorongo and Upper Thomson River areas should be made with care. Further seed source selections should concentrate on those favourable Toorongo populations such as Mt Erica, Mt St Gwinear, and Mt Horsfall and from the Rubicon and Macalister provenances.

Half-sib family selection at Rotoaira showed 6% expected gain in diameter and 7.5% expected gain in form score per standard deviation of selection intensity. Significant family differences for windfirmness were demonstrated and genetic improvement for this trait could also be expected.

Selections averaged 6% diameter gain for half-sib family selection across sites per standard deviation unit of selection intensity. This level of gain equates to a 19% volume increase by selecting the best 20 families. There was a significant family × site interaction caused in one of the sets at least by a relatively different ranking of families at Kaingaroa. An 8% gain can be expected across sites for form score selection of these half-sib families.

Recommendations

An intensive effort at genetic improvement for *E. nitens* in New Zealand (for instance, using controlled crossing) is at present unwarranted and unless commercial interest in this species becomes stronger only simple and low-cost breeding options are justified. However, simple methods of improvement can be quite effective. Improvement for *E. nitens* has continued with:

(1) Widening of the breeding base of central Victorian families by exchange and import of material with Australian agencies.

(2) Open-pollinated mating for the breeding population. Within-family selection was carried out in the Rotoaira trial after a thinning to 350 stems/ha. This thinning is effective in ensuring good pollen parentage for the open-pollinated matings. Selection was done in such a way as to ensure at least some individuals are selected down to rank 50 in the families but comparatively more individuals are selected in the top 20 ranked families.

(3) Half-sib family selection for seed production. After the collection of breeding population families was completed the Rotoaira stand was reduced further to leave the best seed-producing individuals from the top 20 families. The stand was reduced to 100 stems/ha and has been left as a seed production area. Additionally, this same level of improvement is provided by a seed production area using equal amounts of the remaining seed of the 20 best original families. Some combined-index forward selections from top families is added to benefit this mixture. These simple half-sib family improvement efforts can be expected to deliver the 19% volume gains reported in this paper.

(4) Additionally, the 30 combined-index ranked individuals from Rotoaira have been established in a clonal seed orchard in Canterbury. Flower induction techniques will be applied to enhance seed production.

With the vigorous growth of this species, fast generation turnover is very feasible. A further cycle of genetic improvement can be carried out with the next generation of family-tests from the breeding population selections.

ACKNOWLEDGMENTS

We wish to thank D. A. Franklin for his advice and provision of data from the Golden Downs site and D. A. Franklin, C. Raymond, R. D. Burdon, G. R. Johnson, and C. J. A. Shelbourne for comments and criticism.

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