PHENETIC AFFINITIES, VARIABILITY AND CONSERVATION STATUS OF A RARE TASMANIAN ENDEMIC, *EUCALYPTUS MORRISBYI* R.G. BRETT

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(with seven tables and six text-figures)

Eucalyptus morrisbyi is a rare Tasmanian endemic confined to one larger population (c. 2000 mature individuals) and two smaller populations (c. 15 and 16 mature individuals) in southeastern Tasmania. Morphological studies within the informal superspecies "Gunnii" reveal *Eucalyptus morrisbyi* has closest affinities to low altitude populations of *E. gunnii* in southeastern Tasmania and yet has distinct, phenetic differences from that species. Levels of variation in *E. morrisbyi* populations appear comparable to other species despite their small population size. A low frequency of hybridisation occurs with *E. viminalis* in natural stands but is unlikely to have affected the level of variability in the Calverts Hill and Risdon Hill natural populations. In contrast, it is shown that a high frequency of seedlings grown from a planted and a remnant stand of *E. morrisbyi* have affinities with *E. viminalis*. Several of the planted trees appeared to be hybrids and some progeny from phenotypically normal trees also appeared to be of hybrid origin. These results suggest that the genetic integrity of the species may be compromised by injudicious selection of seed for propagation from plantings and could be a major problem for the *ex situ* conservation of this and other rare and endangered species. Recommendations are given to enhance the conservation of this endangered Tasmanian endemic.
Key Words: rare endemic, endangered species, conservation, *Eucalyptus morrisbyi*, Tasmania.

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INTRODUCTION

Eucalyptus morrisbyi R. G. Brett is endemic to Tasmania and is one of the rarest and most endangered of eucalypt species (Curtis & Morris 1975, Pryor & Briggs 1981). It has taxonomic affinities to other Tasmanian endemics, e.g. *E. gunnii*, *E. archeri*, and *E. urnigera* (Jackson 1965) and has been placed in the informal superspecies "Gunnii" with these species and the mainland species, *E. glaucescens* (Pryor & Johnson 1971). This affinity was recognised in the original description of the species (Brett 1938). Members of the superspecies "Gunnii" are mostly high-altitude, subalpine species. In contrast, *E. morrisbyi* is a low-altitude species, occurring less than 100 m a.s.l. This species is of special scientific interest because it has the highest frequency of self-incompatibility recorded in the genus to date (Potts & Savva 1988).

In the present paper, the distribution, population structure and adequacy of conservation of *E. morrisbyi* are examined and the phenetic affinities of *E. morrisbyi* to the other members of the informal superspecies "Gunnii" are studied using both juvenile and adult plants.

MATERIALS AND METHODS

Distribution and Demography

An attempt was made to verify all localities of *E. morrisbyi* indicated on herbaria sheets (HO) and in the literature (e.g. Brett 1938, Gilbert 1968, Chippendale 1988). Plantings of the species in close proximity to natural populations were also examined and recorded, to avoid future confusion with remnants of the natural distribution of the species.

In 1988, the Calverts Hill population of *E. morrisbyi* was divided into 50 × 50 m quadrats as indicated in figure 1(p. 217). In each quadrat in which *E. morrisbyi* occurred, the number of seedlings (< 2 m in height), the number of single stem and multiple stemmed adults and the dominance rating (5 = dominant, 4 = codominant, 3 = subdominant, 2 = few present, 1 = minor [1 or 2 individuals]) of all *Eucalyptus* species were recorded. In addition, the maximum width of the lignotuberous base of each individual of *E. morrisbyi* was measured. The number of individuals comprising the Risdon Hill and Lumeah Point populations was established in 1983 and verified in 1988.

TABLE 1
Adult Morphological Characters Included in Discriminant Functions and Cluster Analyses of *E. morrisbyi*, *E. gunnii/archeri* and *E. urnigera* Populations*

Character	*E. gunnii/archeri* (n=580)			*E. morrisbyi* (n=26)			*E. urnigera* (n=36)			
	Mn (mm)	s.d	s.e	Mn (mm)	s.d	s.e	Mn (mm)	s.d	s.e	F ratio† (2639)
Lamina length	71.7	12.80	0.53	79.4	8.57	1.43	82.8	9.46	1.85	17.5
Lamina width	19.4	3.76	0.16	25.6	6.07	1.01	25.8	3.05	0.60	77.3
Length to the widest point	28.9	5.71	0.24	26.5	4.41	0.74	29.9	3.76	0.74	2.9
Petiole length	18.2	4.10	0.17	20.3	3.61	0.60	23.7	4.04	0.79	33.2
Lamina thickness	0.36	0.06	0.00	0.28	0.03	0.00	0.35	0.05	0.01	25.0
Peduncle length	5.9	1.82	0.08	8.6	2.16	0.36	14.7	4.16	0.82	336.0
Capsule length	7.0	0.94	0.04	9.3	0.92	0.15	11.0	2.03	0.40	301.8
Pedicel length	0.6	0.69	0.03	3.1	1.37	0.23	3.7	2.17	0.43	305.8
Capsule rim width	5.7	0.73	0.03	7.2	0.95	0.16	7.2	1.35	0.27	99.8
Maximum capsule width	6.3	0.63	0.03	7.5	1.17	0.20	8.3	1.21	0.24	169.4
Disk depth (below rim)	1.1	0.46	0.02	1.8	0.49	0.08	3.1	0.72	0.14	344.2

Mn – mean, s.d. – standard deviation, s.e. – standard error.
* Data from Potts & Reid (1985a).
† F-value for difference between the three species; all were highly significant ($P < 0.001$) except for length to widest point.

TABLE 2
Variability within Progeny of a Range of the Informal *Eucalyptus* Superspecies *Gunnii* Populations

Code	Population	Species	Characteristic	Generalised Variance (ln)	s.e.	*n*
CH	Calverts Hill	*E. morrisbyi*	largest extant population	51.1	0.25	64
RH	Risdon Hill	*E. morrisbyi*	small relict population	50.6	0.25	65
HD	Honeywood Drive	*E. morrisbyi*	small relict population	52.7	0.34	48
SP	Snug Plains	*E. gunnii*	low altitude, southern *E.gunnii*	49.2	1.00	17
Al	Alma Tier	*E. gunnii*	low altitude, northern *E.gunnii*	49.7	0.84	20
AH	Jimmys Marsh	*E. gunnii*	high altitude, *E.gunnii* var.*divaricata*	49.6	1.14	15
NU	Alma Tier	*E. urnigera*	northern *E.urnigera*	48.2	0.70	24
MW	Mount Wellington	*E. urnigera*	southern *E.urnigera*	48.4	1.00	17
GL	Mt Baw Baw	*E. glaucescens*	mainland *Eucalyptus* superspecies *Gunnii*	49.5	1.23	14
P	Pensford	*E. gunnii*	low altitude, northern *E.gunnii*	51.8	0.84	20
SB	South Brandum	*E. gunnii*	high altitude, *E.gunnii* var.*divaricata*	47.4	1.45	12
V	Calverts Hill and Risdon Hill	*E. viminalis*	sample sympatric with *E. morrisbyi*	48.6	0.70	24
RP	Royal Park	*E. morrisbyi*	planted	50.3	1.00	17

Adult Morphology

Twenty reproductively mature plants were sampled from the Calverts Hill population and six plants were sampled from the Risdon Hill *E. morrisbyi* population and scored for the suite of adult morphological characters listed in table 1. This data set was combined with that for the *E. gunnii/archeri* populations and northern (Alma Tier) and southern (pooled from Mt Wellington, Mt Field, and Mt Dromedary) *E. urnigera* populations described by Potts & Reid (1985a). The *E. gunnii/archeri* populations were grouped into the five phenetic groups indicated by Potts & Reid (1985a) and the two *E. morrisbyi* populations were pooled. The phenetic dissimilarities between the resulting taxa were examined, using discriminant functions analysis and by single linkage clustering (Sneath & Sokal 1973) of the Mahalanobis' generalised distances (D^2 — Mahalanobis 1936). Analyses were based on the characters indicated in table 1 and were undertaken using the DISCRIMINANT and CLUSTER procedures of SPSSx (SPSS Inc. 1986). The Mahalanobis' generalised distances were calculated as the squared Euclidean distance between centroids in the space defined by the full suite of discriminant functions (see Phillips *et al.* 1973).

Progeny Trial

Six seedlings were grown from each of 12 trees sampled from the *E. morrisbyi* populations at Calverts Hill and East Risdon and from populations encompassing the range of variation in *E. gunnii/archeri* and *E. urnigera* (table 2). In addition, five seedlings from each of seven trees of *E. morrisbyi* planted at Royal Park (Launceston) and six seedlings from each of nine trees of *E. morrisbyi* from along Honeywood Drive near Lumeah Point, were included. The seedlings were grown in individual plastic bags filled with potting mixture, under a 24-hour photoperiod, and arranged in a randomised design with edge rows. After six months, a single leaf was removed from the 10th node and the seedlings were scored for the characters listed in table 3.

The phenetic affinities of the populations, based on the characters indicated in table 3 (but excluding GLAUC), were examined as described for the adult sample. The *E. morrisbyi* samples from Calverts Hill and Risdon Hill were specifically compared using MANOVA and univariate ANOVA. Following Potts & Reid (1985b) an estimate of the total phenetic variability amongst the seedlings in each population was obtained using the generalised variance (i.e. the

TABLE 3
Seedling Characters Scored in the Progeny Trial

Code	Description
LL	Lamina length (mm)
LW	Lamina width (mm)
LWP	Length to the widest point (mm)
BASE	Measure of degree of lobing of the leaf base when cordate (mm)
APEX	Measure of degree of indentation of leaf apex when emarginate (mm)
LAMTH	Lamina thickness (mm) measured using a spring-loaded micrometer
INTER	Distance between the 9th and 11th nodes (cm)
HEIGHT	Seedling height (cm)
NODES	No. of leaf pairs expanding on the main stem (cotyledons = 0)
STVER	Density of verrucae (oil glands) on the stem (0 = smooth, 2 = highest density)
STSQ	Stem shape (0 = round, 3 = square and costate)
ANTH	Development of anthocyanin pigmentation on the seedling stem (0 = green, 2 = red over much of the stem)
SERR	Degree of indentation of the leaf margin (0 = entire, 2 = serrate)
PLATS	Proportion of nodes bearing laterals
GLAUC	Degree of glaucousness (0 green – 4 marked glaucousness extending into stems and old leaves) (only included in hybrid analysis)

determinant of the variance-covariance matrix), which was calculated in an eight dimensional space defined by standardised values of LAMTH, INTER, HT, NODE, PLATS and the first three principal components derived from analysis of the five leaf dimensions (LL, LW, LWP, BASE and APEX). The five univariates were each standardised to a mean of zero and total standard deviation of one. The principal components analysis used the pooled-within-groups correlation matrix and the first three principal components describing variation in lamina size (PC1) and shape (PC2 & PC3) accounted for 93% of the variance. The generalised variance was calculated for each population using the DISCRIMINANT subprogram of SPSSx after multiplying all variables by 100. Approximate standard errors of the natural logarithm of the generalised variance were estimated following Goodman (1968). A single hybrid individual in the Calverts Hill sample was excluded from all these analyses.

In order to examine suspected hybridisation between *E. viminalis* and *E. morrisbyi* a three-group discriminant functions analysis was undertaken using a sympatric sample of *E. viminalis* (RH + CH) and the *E. morrisbyi* populations from Calverts Hill and Risdon Hill. The scores of individuals from these three populations and those grown from small remnant stands and plantings of *E. morrisbyi* (HD and RP) were calculated and plotted on the two discriminant functions derived from this analysis. The probability of group membership was determined and all individuals classified into one of the three groups (*E. viminalis*, CH or RH).

Germination Trial

Seed from the populations of *E. morrisbyi* from Calverts Hill and Risdon Hill and selected *E. gunnii* and *E. urnigera* populations were compared for germinative capacity (GC) and rate of germination, following the procedures outlined by Wiltshire & Reid (1987). The rate of germination was assessed using the mean number of days to germination and the germinative energy index (GEI, Grose 1963) for seeds which germinated over a 21-day period.

RESULTS

The natural distribution of *Eucalyptus morrisbyi* is now restricted to one relatively large stand at Calverts Hill, smaller stands at nearby Lumeah Point and Honeywood Drive, and another small population in the Government Hills, in the East Risdon Nature Reserve (fig. 1).

Calverts Hill

The Calverts Hill population of *E. morrisbyi*, near Cremorne, consists of nearly 2000 adult trees (11.5 ha) within a mixed stand of *E. tenuiramis* and *E. viminalis* of about 14 ha. This *E. morrisbyi* stand is 0.5 km from the coast, is on private property and is surrounded by agricultural land (orchard and pasture). The stand is centred in a gully on the southwest to west face of a gently sloping hill (fig. 1) and extends from about 25 to 80 m a.s.l. The soil type is a shallow (100–200 mm), sandy loam, derived from Jurassic dolerite with some influence of Quaternary aeolian sand deposits.

The climate is mild; the mean maximum of the warmest month is about 23°C and the mean minimum of the coolest month is about 5°C. The average annual rainfall is 520–580 mm (between the Hobart Airport and Rokeby average, Hobart Meteorological Bureau), but the Cremorne area has been subjected to moderate to severe drought conditions for the last seven years. The aspect and location in a gully has protected the larger trees in the centre of the population from drought, but drought stress is evident in individuals from the lower margin of the population. Seedling regeneration within the stand has been restricted by grazing (sheep and possibly rabbits). Many of those individuals that managed to reach a height of about 2 m have died during the drought, especially those in competition with older trees.

Lumeah Point and Honeywood Drive

Lumeah Point extends into Pipe Clay Lagoon, a large, shallow tidal lagoon to the south of Calverts Hill (fig. 1). Sixteen adults are only metres above the shoreline on the southwest shore of the point, 2.2 km from the Calverts Hill population. The trees, growing on a sandy soil derived from Quaternary deposits, are in a narrow coastal reserve surrounded by residential land which is cleared apart from these *E. morrisbyi*, several *E. viminalis* and *E. ovata* and a few *Casuarina* spp.

The relatively large size of these *E. morrisbyi* trees (c. 20m high) suggests that they are remnants of the past natural distribution of the species, rather than planted specimens. The trees appear healthy and 14 out of 16 bear heavy capsule crops. However, limited natural regeneration appears to be occurring, with only nine seedlings found and few saplings of intermediate size. In an attempt to increase the size of this population, some 70 seedlings were planted in the spring of 1987 as part of an Australian National Parks and Wildlife Service project to increase *E. morrisbyi* numbers. It was noted, however, that a proportion of the seedlings surviving in 1990 appeared to be of abnormal phenotype.

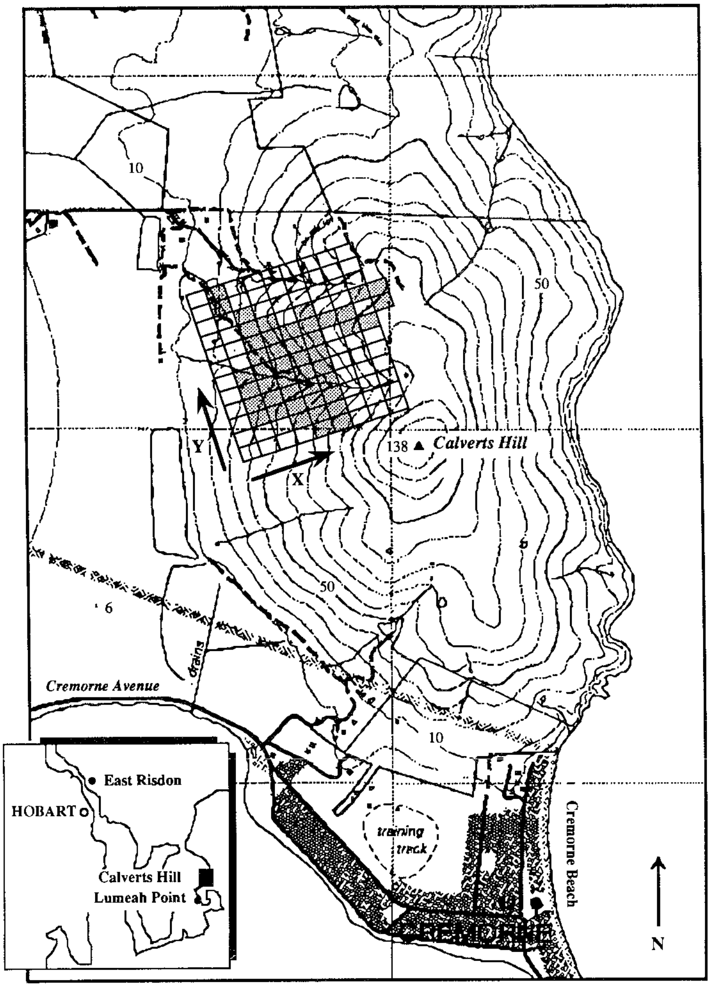


FIG. 1 — Locations of populations of Eucalyptus morrisbyi: *two, very small, at Risdon Hill and Lumeah Point; one, larger, at Calverts Hill). A grid of the scored 50 × 50 m quadrats is superimposed on a magnified portion of the 1:25 000 Tasmap series, Cremorne.*

Gilbert (1968) noted that a few large trees were to be found along Honeywood Drive. These were located 700 m from the Lumeah Point population. Two large trees were in an avenue of other species (predominantly *E. ovata*) by the roadside, and ten trees, 7–9 m in height, were found on adjacent private property. These trees had regenerated from coppice, with the original trees destroyed by felling, fire or both. The numerous saplings (to 5 m) that surround a nearby waterhole and line the roadside appear to be a mixture of natural regeneration and planting.

Risdon Hill

The Risdon Hill population, in the Government Hills, consists of 16 reproductively mature individuals in an area of only 25 x 25 m (< 0.1 ha). This stand, fonnally protected in the East Risdon Nature Reserve (described in Brown & Bayly-Stark 1979), is surrounded by *E. viminalis*, *E. globulus*, and *E. amygdalina*. The *E. morrisbyi* stand is in a gully on the SSW (190°N) face of a moderately sloping hill, 80 m a.s.l. The soil type is sandy loam of moderate depth (20–50 cm).

The mean maximum temperature of the warmest month is 22°C in January and the mean minimum temperature of the coolest month is 4°C in July; frosts occur, on average, from one to five days a month over winter (Risdon station, Hobart Meteorological Bureau). The mean annual rainfall is 589 mm, but the general area has been subject to periodic drought conditions since at least 1980, during which time the stems of the only three large, emergent trees (c. 20 m height) appear to have been severely stressed and two have subsequently died.

Other Populations

Due to their rarity, attractive foliage and moderate size, *E. morrisbyi* are to be found as specimen trees or ornamentals in a variety of locations throughout Tasmania, where they grow on a range of soil types.

Some 30 trees have been planted at the base of Tunnel Hill, beside the Tasman Highway. These trees are from 3–4 m in height (perhaps ten years old) and none appear to have yet reached reproductive maturity.

Other patches of *E. morrisbyi*, and single trees, are to be found in the Cremorne area, near Calverts Hill, but it is difficult to distinguish between those isolates that have occurred through long-distance dispersal, those that have been planted and those that are relicts of a wider past distribution. An avenue of 32 reproductively mature trees is to be found near the junction of the South Arm road and the Cremorne road and is probably the avenue planted by J.R. Morrisby, described in the original description of the species by Brett (1938). There has probably been some natural regeneration from these trees with at least two second-generation individuals (1 and 4 m high) in the stand.

Two *E. morrisbyi* trees on the South Arm road, c. 200 m north of the Clifton Beach Road turnoff, may be remnants of a population described in herbarium specimen notes by L.A.S. Johnson in 1965 and, no doubt, other single trees exist in the Cremorne area, along roadsides and isolated in farmland. However, the population from which the type specimen was described ("... confined to a thin belt of trees skirting the beach at the junction of the South Arm and Clifton Beach roads, S.E. Tasmania" — Brett 1938) has not been sighted during this study. There are no clear records lodged in the Tasmanian Herbarium (HO) since the 1960's and the population may have been destroyed by the 1967 bushfire.

The record in HO of a specimen collected in 1959 on the Port Davey track (southwestern Tasmania) has not been re-confirmed.

An initiative by the Australian National Parks and Wildlife Service (Fazackerly 1987) led, in 1987, to the propagation of some 1400 *E. morrisbyi* seedlings and the establishment of 33 small copses, ranging in size from 7 to 159 seedlings (mean 38), along roads and on private property throughout the Cremorne area. The seedlings were grown from a small number of adults, two from the Calverts Hill population, two from Lumeah Point, and an unknown number from Honeywood Drive.

Past Distribution

The present distribution and herbarium records suggest that the populations at Calverts Hill and Lumeah Point represent the remnants of a wider distribution in the recent past. The Calverts Hill population extended to the eastern side of the hill only 20 years ago, but contracted to the western side when grazing and clearing followed the devastation of the 1967 bushfire (Gilbert 1968). In addition to this contraction, it is probable that small, outlying populations have become extinct in the Cremorne area in the last 20 years. The population at Clifton Beach turnoff, for example, has not been recorded since the 1967 bushfire. However, it is likely that even greater areas of *E. morrisbyi* were destroyed in the preceding century. Brett (1938) reported that "Messrs A. and M. Morrisby assert that the species formed a dense scrub of at least 50 acres [20 ha] in extent before clearing was undertaken". This suggests that the Calverts Hill population may have extended down the slope of the hill to Rushy Lagoon. Indeed, the individuals at Lumeah Point, Honeywood Drive and the extinct population at Clifton Beach turnoff, suggest that *E. morrisbyi* was once widespread on the eastern half of South Arm and may have extended as a mosaic of small populations, or as a mixed eucalypt forest, from the edges of Rushy Lagoon to Clifton Beach. These areas were cleared for grazing before Brett's description of the species in 1938.

It is possible that the Risdon Hill and Calverts Hill populations of *E. morrisbyi* were once part of a single population. They are now separated by a distance of 20 km and have probably been genetically isolated for several thousand years, perhaps since the last glaciation when they may have occupied what is now the bed of the River Derwent and Ralphs Bay.

Demography

The Calverts Hill population is the only remaining sizeable stand of this species. The size of the population has largely been determined by past clearance of the surrounding area for grazing, and the demographic structure of the population is still being affected by grazing. However, the primary influence on the population dynamics and the growth form of the trees was the last bushfire, in February 1967. The population currently consists of 1915 adult individuals. Of these, 16 stems (≥15 m in height) appear to have survived the 1967 fire (fig. 2) and there are 1005 *E. morrisbyi* lignotubers (≥ 200 mm diameter) that coppiced to produce multi-stemmed trees. The remaining 910 are single-stemmed trees, probably from reproductive regeneration immediately following the fire and, to a lesser extent, from continuous regeneration since the fire. It is likely that the stand was also burnt in the late 1940's or 1950's, as Gilbert (1968) stated that prior to the fire the stand consisted mainly of saplings. This is supported by the large number of lignotubers in the 30–40 cm diameter classes shown in figure 3. However, reproductive regeneration since that time has been limited. At present, there are only 328 seedlings (including saplings to 2 m) in the stand. As can be seen from table 4, most of this regeneration is restricted to the centre of the stand and 209 of the 328 (64%) seedlings are found in only five central quadrats (1.25 ha). The density of the adults is also highest in this central region and the intense competition from these adults would be expected to decrease the chance of seedlings in this region surviving to maturity.

In the Risdon Hill population there are three emergent trees of 20 m height (two of these may now be dead), 13 large lignotubers (6 × 600–700 mm, 3 × 800–900 mm, 4 × >1 m diameter) with coppice stems of about 7 m height, a single tree-form of 4 m height, and a large number of immature individuals (63 <1 m, and 109 >1 m high). There appears to have been a continuing decline in population numbers in the immediate past as Brown & Bayly-Stark (1979) indicated that ten large trees were extant in 1987 and there was also "abundant seedling and coppice regeneration".

The active exclusion of fire from most of the stand since at least 1967 has allowed the establishment of the seedlings regenerated by earlier fires and has allowed coppice regeneration to reach a mean height of 7 m. However, the diameter of the coppice stems is probably still below the threshold for survival of a moderately intense fire. At present, the capsule crop within the stand is light, and a fire-free period is necessary for the accumulation of a sizeable seed bank in the crown and to allow established seedlings and coppice stems to reach sufficient size to enable regeneration from lignotubers and epicormic shoots respectively. Undoubtedly, many of the seedlings in the stand will be lost through competition. Many seedlings are also in marginal situations and their growth may be restricted by the surrounding trees of other *Eucalyptus* species. In 1979, the population appeared to be endangered by an infestation of the parasitic vine *Cassytha pubescens* (Brown & Bayly-Stark 1979). A plot of 12 x 12 m was cleared of *Cassytha* at that time and *Cassytha* no longer appears to pose a major threat.

Ecological and Floristic Variation at Calverts Hill and Risdon Hill

Eucalyptus morrisbyi is the dominant species on the southeastern to western slopes of Calverts Hill, with *E. viminalis* and *E. tenuiramis* as sub-dominants. With changes in aspect from west to northwesterly, and near the top of the hill, *E. tenuiramis* and *E. viminalis* become increasingly dominant and displace *E. morrisbyi*. The associated plant community has been highly disturbed and ground cover species have been replaced by introduced grasses that can withstand grazing and by unpalatable sedge species such as *Lomandra longifolia* and *Lepidosperma laterale*. Similarly, understorey and shrub species consist of *Bursaria spinosa* and, more rarely, *Acacia melanoxylon*, *A. mearnsii* and *Casuarina stricta*. The community resembles an open woodland,

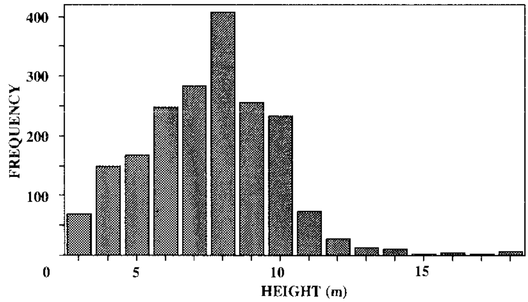


FIG. 2 — Frequency histogram of the height of the adult Eucalyptus morrisbyi *at Calverts Hill.*

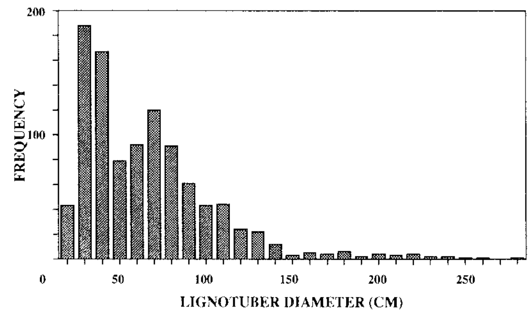


FIG. 3 — Frequency histogram of the diameter of the adult Eucalyptus morrisbyi *lignotubers at Calverts Hill.*

TABLE 4
The Number of (a) Adults and (b) Seedlings of *E. morrisbyi* at Calverts Hill*

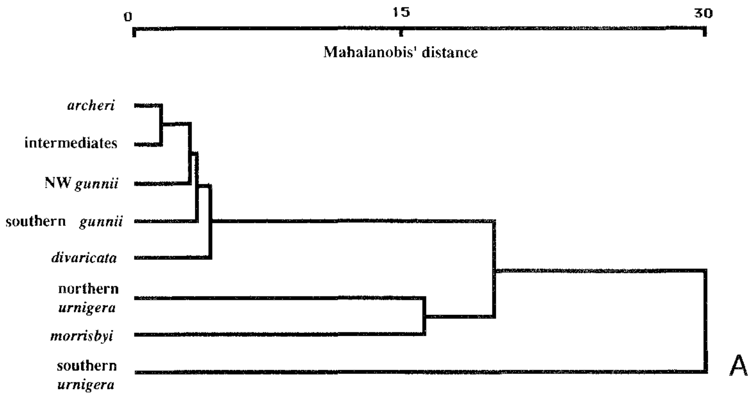
(a) No. of adults

												Total
	11	-	3	-	-	-	-	-	-	-	-	3
	10	-	4	-	-	-	-	-	-	-	-	4
	9	-	-	11	-	-	-	-	-	-	-	11
	8	-	-	87	2	-	2	-	-	48	-	139
Y	**7**	-	-	67	25	3	1	5	4	-	2	107
	6	-	-	57	65	21	12	-	4	1	11	171
	5	-	15	37	74	109	12	-	-	-	-	247
	4	-	12	6	47	169	81	-	-	-	-	315
	3	-	8	37	206	335	49	-	-	-	-	635
	2	-	5	14	87	50	1	-	-	-	-	157
	1	-	-	-	48	71	3	-	-	-	-	122
	0	-	-	-	-	3	1	-	-	-	-	4
	-1	-	-	-	-	-	-	-	-	-	-	0
		-1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
TOTAL		0	34	278	264	643	567	59	8	49	13	1915
						X						

(b) No. seedlings

	11	-	-	-	-	-	-	-	-	-	-	0
	10	-	-	-	-	-	-	-	-	-	-	0
	9	-	-	1	-	-	-	-	-	-	-	1
	8	-	-	3	-	-	-	-	-	2	-	5
Y	**7**	-	-	9	-	-	-	-	8	5	-	22
	6	-	-	1	-	1	-	-	1	3	-	6
	5	-	-	1	3	13	6	-	-	-	-	23
	4	-	-	50	26	10	-	-	-	-	-	86
	3	-	-	3	44	51	11	-	-	-	-	109
	2	-	-	-	38	13	1	-	-	-	-	52
	1	-	-	-	11	9	1	-	-	-	-	21
	0	-	-	-	-	3	-	-	-	-	-	3
	-1	-	-	-	-	-	-	-	-	-	-	0
		-1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
TOTAL		0	0	15	56	133	92	13	9	10	0	328
						X						

* The x and y co-ordinates correspond to the intercepts of the lines on the grid in figure 1. Each quadrat measures 50 x 50 metres.



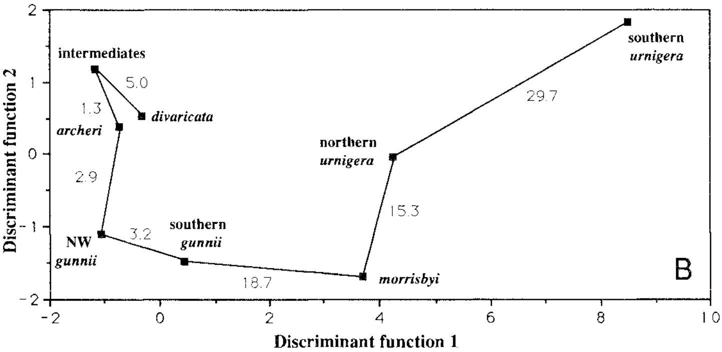


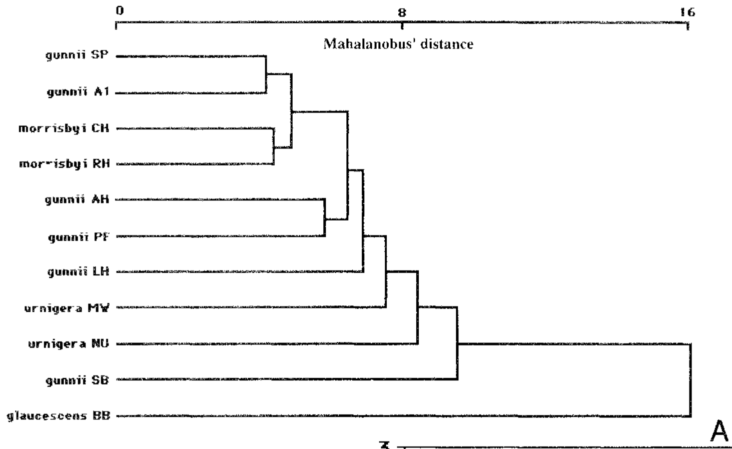
FIG.4 — (A) single linkage dendogram and (B) discriminant function ordination of Eucalyptus morrisbyi, E. urnigera *(southern and northern samples) and five phenetic groups of* E. gunnii/archeri, *based on adult leaf and reproductive characters. The minimum spanning tree with Mahalanobis' distances is indicated in (B).*

with a very closely grazed grass cover, or sedges to 0.3 m in the wetter gully.

The Risdon Hill *E. morrisbyi* population is also centred on a southwest-facing gully. The vegetation has not been subjected to high grazing pressure, however, and may be more representative of the natural plant community associated with *E. morrisbyi*. It has been described in detail by Brown & Bayly-Stark (1979). As at Calverts Hill, *Acacia melanoxylon* is to be found as a subdominant within this stand. This species is usually restricted to wetter conditions than are found in the surrounding habitat and may indicate a crucial environmental parameter limiting the distribution of *E. morrisbyi*.

Variation in the Adult Phenotype

The means of eight of the eleven leaf and fruit characters measured from adult *E. morrisbyi* trees are intermediate between those of *E. gunnii/archeri* and *E. urnigera* (table 1). For nine of these characters, the *E. morrisbyi* mean values are significantly ($P < 0.001$) larger than the corresponding means of *E. gunnii/archeri*, the exceptions being the length to the widest point of the leaf (not significantly different) and the lamina thickness (thicker in the higher altitude species). In contrast, the mean values of 7 of these 11 characters were smaller ($P < 0.001$) in *E. morrisbyi* than those of *E. urnigera*. The dendrogram and discriminant functions ordination in figure 4 clearly indicate that the adult morphology of *E. morrisbyi* is distinct from that of the *E. gunnii/archeri* complex and from the two *E. urnigera* samples. In adult morphology, *E. morrisbyi* is intermediate between *E. gunnii/archeri* and *E. urnigera* and has closest affinities to the northern population of *E. urnigera* ($D^2 = 15.3$) and southern *E. gunnii* ($D^2 = 18.7$). The large difference between the *E. urnigera* samples and the early linking of the northern sample with *E. morrisbyi* is mainly a consequence of the fact that only extreme morphs of *E. urnigera* were sampled.



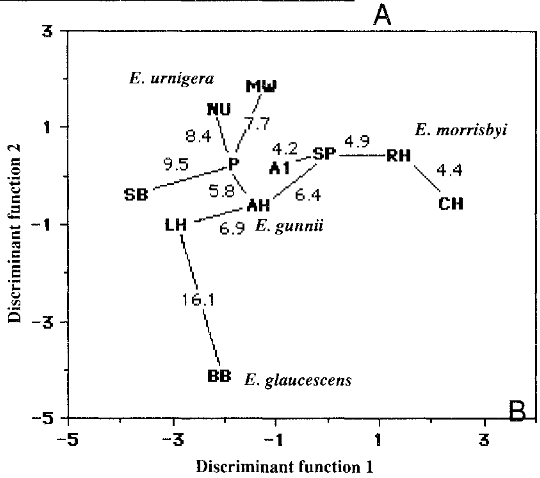


FIG.5 — (A) Single linkage dendogram and (B) discriminant function ordination of Eucalyptus morrisbyi, E. urnigera, E. glaucescens, *and* E. gunnii *populations based on seedling characters. The minimum spanning tree with Mahalanobis' distances is indicated in (B). See table 2 for population codes.*

Seed Germination

There is a marked difference in the mean time to germination and, hence, in germinative energy index (GEI) between seed from low altitude populations of *E. morrisbyi* and *E. gunnii* (RH, CH and SP) and that of high altitude *E. gunnii* and the *E. urnigera* populations (table 5). There is a small but significant ($P < 0.001$) difference in the number of days to germination of the two *E. morrisbyi* populations, with seed from the Calverts Hill population germinating nearly a day earlier than the Risdon Hill seed, but both germinated vigorously. Although a much smaller sample was used for the *E. gunnii* populations, the germination behaviour of the lowest altitude population of *E. gunnii* (Snug Plains) was identical to that of the Risdon Hill *E. morrisbyi* and different from the other *E. gunnii* populations (table 5).

Progeny Trial

Variation Between the Risdon Hill and Calverts Hill Populations

An estimate of the magnitude of genetic variation between the Risdon and Calverts Hill populations was obtained from the progeny trial where seedlings were at the same ontogenetic stage and grown in a common glasshouse environment. Such an estimate is valuable as it suggests the extent of differences that may have arisen in the smaller population due to genetic drift, inbreeding or introgressive hybridisation. The degree of genetic variation between the two populations has implications for the conservation strategy of the species. Table 6 summarises the differences between the progeny from each population. The trial indicates that significant genetic differences occur between the large Calverts Hill population and small Risdon Hill population of

TABLE 5
Analysis of Variance of *E. morrisbyi* Progeny from Two Populations

Variable*	Calverts Hill Mean (n=64)	Calverts Hill ±sd (n=65)	Risdon Hill Mean	Risdon Hill ±sd	F ratio (1127)
LL	27.1	3.69	24.1	3.48	24.32†
LW	34.2	5.53	32.6	4.67	2.97
LWP	10.1	1.76	9.4	1.59	24.02†
EMARG	1.7	1.03	2.1	0.08	4.53‡
APEX	0.9	0.72	0.9	0.68	0.00
LAMTH	0.15	0.02	0.17	0.02	22.92†
INTER	9.3	2.06	9.7	1.86	0.91
HEIGHT	78.2	15.82	76.7	13.78	0.57
NODES	20.1	2.84	18.6	2.68	9.84‡
STVER	1.9	0.27	2.0	0.00	6.51§
ANTH	0.0	0.18	0.1	0.29	6.07
STSQ	1.7	0.47	2.0	0.31	21.48†
SERR	1.9	0.33	1.8	0.39	0.19
PLATS	0.4	0.17	0.3	0.14	23.83‡

* Seedling characters (14) included in discriminant function analysis, coded as table 3.
† $P<0.001$
‡ $P<0.01$
§ $P<0.05$

TABLE 6
Seed Germination Trial

Population	Altitude (m)	Days to germination Mean	sd	n	GC	GEI
E. morrisbyi						
Calverts Hill	80	5.8	1.59	273	1.00	0.75
Risdon Hill	80	6.4	1.25	236	1.00	0.70
E. gunnii						
Snug Plains	600	6.4	1.60	20	1.00	0.70
Alma Tier.	930	9.9	2.58	32	1.00	0.48
Pensford	960	9.4	2.98	20	1.00	0.51
Jimmys Marsh	1010	8.1	2.45	37	1.00	0.59
South Brandum	1040	8.2	2.53	18	0.95	0.59
E. urnigera						
Mount Wellington	500	10.9	2.23	10	0.77	0.41
Alma Tier	1010	8.5	1.87	36	0.92	0.56
E. viminalis						
Calverts Hill	80	6.7	2.20	39	0.76	0.58
Risdon Hill	80	8.2	2.42	38	1.00	0.69

GC – germinative capacity; GEI – germinative energy index; n – number of seeds germinated.

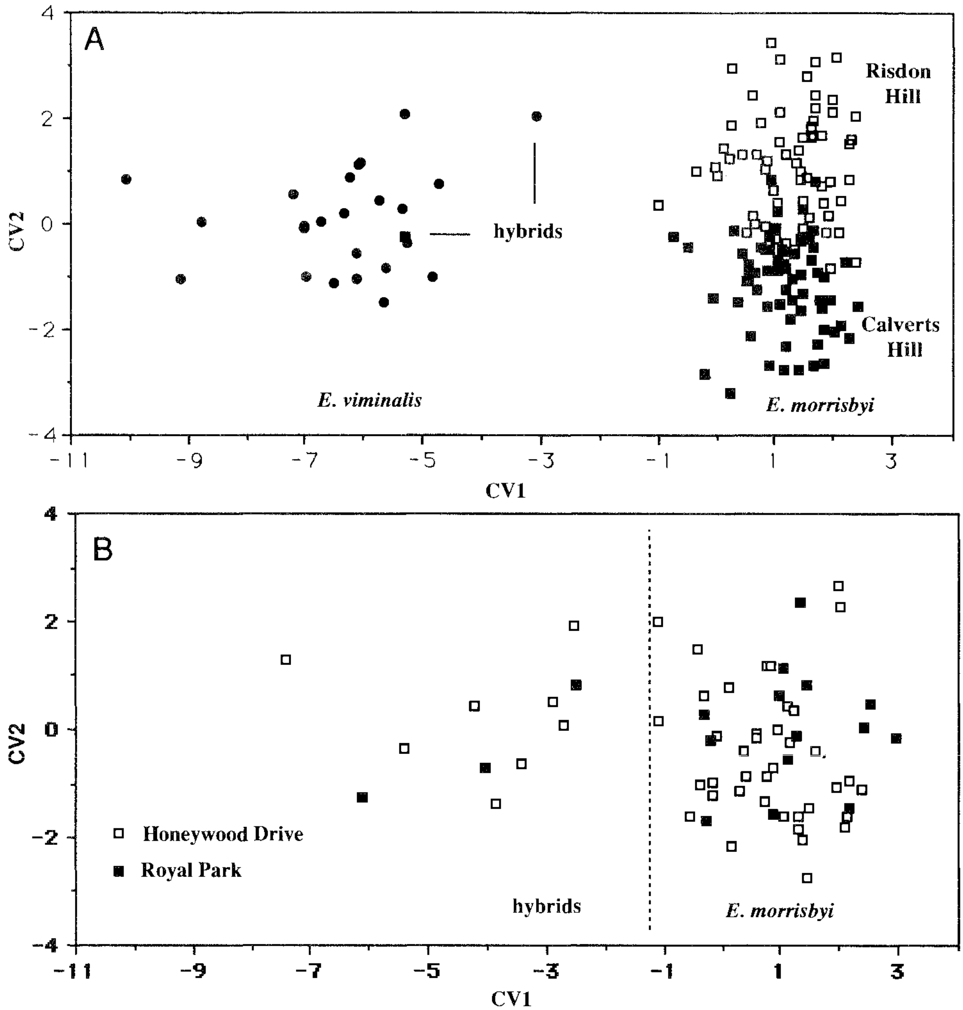


FIG.6 — Hybridisation between Eucalyptus morrisbyi *and* E. viminalis *in (A) two natural populations and (B) a planted stand and a small relict stand. The figure shows the ordination of seedlings on the two discriminant functions separating samples of* E. viminalis *and two natural populations of* E. morrisbyi, *using all characters indicated in table 5. Scores on these axes were also calculated for seedlings from Honeywood Drive and Royal Park but these samples were not used to derive the discriminant functions.*

E. morrisbyi. The two populations differ significantly ($P < 0.05$) for 8 out of the 14 characters shown: the progeny from Calverts Hill have longer, thinner, less emarginate leaves and have slightly rounder, less verrucose stems than the Risdon Hill population. Seedlings from the Risdon Hill population expanded fewer (NODES $P < 0.01$) and smaller leaves (e.g. LL $P < 0.001$; LW n.s.) than those from Calverts Hill, but there was no significant difference in seedling height. The two populations were clearly differentiated using discriminant function analysis (MANOVA, $P < 0.001$) and, even at the individual level, there is little overlap along the discriminant function separating the two populations (fig. 6A). Indeed, using the discriminant functions shown in figure 6, only 6.2% and 21.5% of the seedlings from Calverts Hill and Risdon Hill respectively were misclassified (table 7).

TABLE 7
Percentage of Seedlings Classified by Discriminant Function Analysis as having Closest Phenetic Affinities to *E. viminalis* or *E. morrisbyi*

Actual group	N	Predicted group (%)		
		E. morrisbyi CH	*E. morrisbyi* RH	*E. viminalis* RH + CH
Natural populations				
E. morrisbyi **CH** (Calverts Hill)	65	92.3	6.2	1.5 (1.5)*
E. morrisbyi **RH** (Risdon Hill)	65	21.5	78.5	0.0 (0.0)
E. viminalis	24	0.0	0.0	100.0
Plantings and populations not included in analysis				
E. morrisbyi **RP** (Royal Park)	17	35.3	52.9	11.8 (17.6)
E. morrisbyi **HD** (Honeywood Drive)	48	60.4	22.9	16.7 (16.7)

CH – from Calverts Hill; RH – from Risdon Hill.
* Percentage of individuals outside the normal range of variation in natural populations of *E. morrisbyi* and considered of hybrid origin indicated in parentheses.

Comparison with Populations of Closely Related Species

In the space defined by the 14 seedling characters all of the populations of *E. gunnii*, *E. morrisbyi*, *E. urnigera* and *E. glaucescens* were clearly differentiated with all but one (LH vs AH) of the Mahalanobis' distances highly significant ($P < 0.001$). The differentiation amongst these populations is summarised in figure 5. The degree of differentiation between species compared to variation between populations within species (fig. 5) contrasts markedly with the adult analysis (fig. 4) and is consistent with the emphasis on adult reproductive characters in differentiating these closely related endemics. The analysis clearly indicates that the mainland member of the informal superspecies "Gunnii", *E. glaucescens,* is markedly different from the Tasmanian endemics in seedling characteristics.

While statistically significant, the degree of genetic differentiation between the Calverts and Risdon Hills populations of *E. morrisbyi* is relatively small when compared to the level of differentiation between populations within *E. gunnii* and *E. urnigera*. For example, the Mahalanobis' distance (D^2) between the two populations of *E. morrisbyi* was 4.4, only marginally greater than the distance between the most similar populations of *E. gunnii* (SP vs A1 = 4.2). However, the average distance between all populations of *E. gunnii* was 10.4 and the maximum distance between populations of the single subspecies (spp. *gunnii*) was 19.2 despite encompassing only two of the five phenetic groups identified by Potts & Reid (1985a). Even the two Alma Tier populations of *E. gunnii* (A1 and AH), which are relatively large and separated geographically by only 1.5 km, are more differentated ($D^2 = 6.4$) than the two populations of *E. morrisbyi* .

The *E. morrisbyi* populations from Calverts Hill ($D^2 = 9.0$) and Risdon Hill ($D^2 = 4.9$) are most similar to the low altitude *E. gunnii* population from Snug Plains in seedling phenotype. The latter is the closest *E. gunnii* population to *E. morrisbyi* and is situated approximately 29 and 26 km from the *E. morrisbyi* populations at Risdon and Calverts Hills respectively. In fact, the seedling phenotype of the Snug Plains *E. gunnii* appears to be more similar to that of the Risdon Hill *E. morrisbyi* than it is to the majority of *E. gunnii* populations, although this is not the case for the adult phenotype. In all cases, the population of *E. morrisbyi* from Risdon

Hill is more similar to populations of *E. gunnii* and *E. urnigera* than is the population from Calverts Hill and it appears to be intermediate between the Calverts Hill population and the Snug Plains *E. gunnii* (fig. 5b). *E. morrisbyi* does not appear intermediate between *E. gunnii* and *E. urnigera* in seedling morphology. Rather, the *E. morrisbyi*, *E. urnigera* and *E. glaucescens* populations deviate from the main core of the *E. gunnii* populations in completely different directions. Nevertheless, *E. morrisbyi* consistently shows affinities to southern *E. gunnii* in both adult and seedling analyses.

Population Variability

Estimates of the generalised variance for progeny from each population are given in table 2. These estimates of phenotypic variability still incorporate genetic and environmental components. However, as the seedlings were grown in a randomised design in a common glasshouse environment, it is assumed that the level of environmental variance is similar for all populations and that any differences in the generalised variance between populations reflects true differences in genetic components of variability.

While there is a trend for the total variability amongst seedlings from the small Risdon Hill population of *E. morrisbyi* to be less than that in the large population at Calverts Hill, this difference is not significant ($P > 0.05$). Furthermore, there is no evidence from this trial that either population of *E. morrisbyi* is genetically depauperate and in fact estimates of the generalised variance would suggest that the Calverts Hill population in particular may be more variable genetically than many of the large, natural populations of both *E. gunnii* and *E. urnigera*. The sample of seedlings grown from the *E. morrisbyi* planting at Honeywood Drive was significantly ($P < 0.05$) more variable than any of the natural populations of *E. morrisbyi* and this would appear to be the result of hybridisation with *E. viminalis*.

Hybridisation

E. morrisbyi is sympatric with *E. viminalis* at both Risdon Hill and Calverts Hill and with *E. globulus* at Risdon Hill, and it is in relatively close proximity to *E. ovata* at Calverts Hill and Honeywood Drive. The flowering period of *E. morrisbyi* overlaps that of *E. viminalis* (Potts 1989) and controlled pollination studies have indicated that the two species can successfully cross (Potts, pers. comm.). Despite the lack of strong reproductive barriers, the level of F_1 hybridisation in natural populations is low and only 1.5% of progeny from *E. morrisbyi* adults were considered to be of hybrid origin. Furthermore, despite suggestions of genetic swamping of the small population of *E. morrisbyi* at Risdon Hills by *E. viminalis* genes (Brown & Bayly-Stark 1979), there was no evidence of convergence of this population towards *E. viminalis* (fig. 6a).

In contrast, many of the planted individuals of *E. morrisbyi* at Royal Park (in Launceston) lay outside the range of phenetic variability found in natural stands of *E. morrisbyi* and were intermediate in phenotype to *E. viminalis*. The progeny from this planted population contained a large percentage (18%) of seedlings of intermediate or backcross morphology (table 7). The progeny from the Honeywood Drive population contained a similarly high proportion of seedlings with abnormal morphology.

DISCUSSION

The morphometric study of adult leaf and fruit characters reveals that *E. morrisbyi* is phenetically distinct from the *E. gunnii/archeri* complex, although many of the differences are largely a continuation of the clinal trend in the complex for an increase in morphological character size and decreasing lamina thickness with decreasing altitude of the population. *E. morrisbyi* appears to be intermediate between southern *E. gunnii* and northern *E. urnigera* for many adult morphometric characters. The progeny trial reveals a much closer degree of morphological similarity in the seedling morphology of the species from the informal superspecies "Gunnii" than was apparent in the adult morphology, with only the mainland species, *E. glaucescens*, differing markedly (fig. 5). The phenetic relationships between the populations suggest that for both adult and seedling characteristics *E. morrisbyi* has close affinity with the low-altitude, southern *E. gunnii*. The same affinity between these two taxa was noted in another progeny trial that included *E. cordata* (Potts 1989). The germination behaviour of seed from the *E. morrisbyi* populations and from the low altitude, southern *E. gunnii* was also similar, with the higher altitude provenances and the *E. urnigera* requiring longer to germinate.

The affinity in capsule size of *E. morrisbyi* with the northern *E. urnigera* does not appear to be a reflection of convergent evolution due to similar habitats (e.g. altitude). Rather, it is more likely that the intermediate morphology of northern *E. urnigera*, southern *E. gunnii* and *E. morrisbyi* reflects a common ancestry. In this case, the relatively small capsule size of northern *E. urnigera* is a primitive character, and the large capsule of the southern *E. urnigera* is a relatively recently derived condition. One can only speculate on the origins of the group, but past hypotheses have included the suggestion that *E. morrisbyi* developed as a distinct species as the surviving coastal part of a population of eucalypts from which *E. gunnii* was derived (Pryor & Briggs 1981). This hypothesis is consistent with the morphological affinities found with southern *E. gunnii* and the suggestion by Potts & Reid (1985b) that during the last glacial period, *E. gunnii* was distributed in a "south-eastern glacial refugium" and, as a consequence of this large-scale movement in the flora, small populations were inevitably isolated at the ecological and geographical extremes of the species' margins.

Genetic Variability and Population Size

The Risdon Hill *E. morrisbyi* population is extremely small and effectively isolated from conspecific gene migration by a geographical distance of 20 km. Estimates of the generalised variance derived from the progeny trial suggest that there is no significant difference in variability between the larger Calverts Hill population and the Risdon Hill population. Indeed, the level of variability in both populations of *E. morrisbyi* appears to be comparable to that found in progeny from large natural populations of *E. gunnii* and *E. urnigera*. Recent work on the reproductive biology of *E. morrisbyi* (Potts & Savva 1988) suggests that self-incompatability may decrease the degree of inbreeding and, thereby, increase the effective size of the breeding population. Nevertheless, the small population has probably been sustained for a number of generations and so it would appear inevitable that inbreeding between consanguine individuals must comprise a large part of the genetic exchange in the population. However, there is no evidence from the progeny trial to suggest that inbreeding and genetic drift have led to a loss of variation in the smaller population in the Risdon Hills or to changes in phenotype associated with a loss of fitness.

In contrast, the Calverts Hill population has suffered a marked reduction in size due to agricultural development in the recent past. However, the population, on the criterion of both Namkoong (1984) and Frankel & Soulé (1981), still seems large enough to avoid both the long and short-term deleterious effects of inbreeding, which may account for the relatively high variability in the population. Alternatively, as suggested by Prober *et al.* (1990) for remnant populations of *E. parvifolia*, insufficient time may have elapsed since the population was reduced in size for the effects of inbreeding to be manifest. This is unlikely to account for the relatively high level of phenetic variability in the small population in the Risdon Hills.

Hybridisation

It has been shown that hybridisation is possible between *E. morrisbyi* and sympatric *E. viminalis*. However, there is no evidence of convergence of the smaller Risdon Hill population towards *E. viminalis*. Indeed, it is the smaller population that has the closer affinity to *E. gunnii* in both germination behaviour and in the multidimensional space defined by the seedling characters. Therefore, it is unlikely that introgression of *E. viminalis* genes has played a role in the maintenance of variability in this *E. morrisbyi* population.

Introgressive hybridisation does, however, appear to be possible in planted stands of *E. morrisbyi* trees. Some trees at Royal Park appear to be hybrids between *E. morrisbyi* and *E. viminalis* and some progeny from both the Honeywood Drive and Royal Park trees possess abnormal phenotypes suggesting hybrid origin. If the barriers to second-generation hybridisation are weak, then subsequent generations from these trees will be a melange of the genetic material from the two species. Therefore, these stands, and similar ornamental plantings, may not contribute to the preservation of the gene pool of this rare and endangered species. Hybridisation with proximal species may lead to genetic degradation in ornamental and other *ex situ* plantings, and genetic integrity of the species may be compromised by the injudicious selection of seed for propagation. This should be a consideration when planning *ex situ* conservation of rare and endangered species.

Conservation Status

Undoubtedly, *E. morrisbyi* is in a precarious position. It is one of the most endangered of eucalypt species, being found in only three natural stands. Despite the official protection afforded by its status within a Nature Reserve, the Risdon Hill population is so small and in such an ecologically tenuous position that its continued existence cannot be guaranteed. Similarly, the small Lumeah Point population is in a marginal environment where it is susceptible to drought, salt-laden winds and the risk of vandalism. The few trees at Honeywood Drive are largely on private property and are not regarded by the present owner as being of special value. Although larger and more ecologically secure than the other stands, the Calverts Hill population has no formal protection. It is being eroded by marginal encroachment and impaired reproductive and vegetative regeneration, and is vulnerable to a change in land use.

This stand is used by the owner as a woodlot (for personal use) and for rough grazing of sheep. Principally, dead stems are cut for fuel, although some live stems are sacrificed each year. This, in itself, does not pose a serious threat to the population but it would be preferable if the other species in the stand (*E. viminalis* and *E. tenuiramis*) were removed, rather than the *E. morrisbyi*, or an alternative wood supply provided. Similarly, grazing by sheep does not present a threat to established trees but it does inhibit regeneration. This negative impact on the stand is offset by the reduction in undergrowth and, consequently, the reduction in the risk (and intensity) of fire damaging the population. The optimal situation would be to exclude stock from portions of the stand until seedlings reached a height at which they could withstand the effects of grazing. This could be undertaken around the periphery of the population as well as in the more open areas within the stand to counteract the inevitable attrition of the peripheral individuals.

The vulnerability of the stand to changes in land use cannot be over-emphasised. At present, the owner has the right, and capability, to clear as much of the stand as he wishes. In the early 1980's, a system of waterholes was established around the lower margin of the population and during this operation some *E. morrisbyi* were probably destroyed. More recently, *E. morrisbyi* regenerating by coppice shoots testifies to the removal of trees from one area within the stand. The owner regards the stand as a valuable resource but perhaps not as an invaluable one.

Like Calverts Hill, the Risdon Hill population is regenerating to maturity following fire. This area has been burnt relatively frequently over the last two centuries of European settlement, to the extent that adjacent areas dominated by *E. risdonii* are burnt with an average rotation of less than five years by design, arson or accident. Implementation of the Meehan Ranges Fire Management Plan since 1983 has successfully attempted to exclude fire from the *E. morrisbyi* stand in the Risdon Hill Nature Reserve. For example, a wildfire burnt up to the boundary of the population in the 1986–87 summer, but was prevented from damaging the stand.

CONCLUSION

This study has shown that *Eucalyptus morrisbyi* has a unique and coherent genetic complement and is deserving of its specific status. This genetic resource should be conserved. Although the gene pools of the small populations appear to be relatively resilient to the depauperating effects of inbreeding, all three populations are at risk from physical disturbance, and the largest population is at risk from changes in land use that could take place overnight. The largest population of *E. morrisbyi*, Calverts Hill, should be protected by legislation, with appropriate compensation to the landholder. However, even this is not sufficient to ensure survival of the species. Present ornamental plantings of trees are also inadequate insurance against extinction, since they are of unknown origin, certainly not representative of the full range of genetic diversity in the species, and have been shown to be vulnerable to genetic degradation through hybridisation. The establishment of several *ex situ* conservation stands of the species is highly recommended. These plantations should be relatively large (i.e. ≥1000 individuals), should include seedlings from as large a number of trees as possible from throughout the natural population, and should be relatively isolated from potentially interbreeding species. Conservation stands should follow a common seed orchard design with families arranged in a single-tree plot randomised block design to minimise inbreeding (e.g. Moran *et al.* 1989). Where population differences have been demonstrated, reproductively isolated stands should be established from each natural population to form sublines in order to perpetuate the genetic structure in the species. In the present case, such seed orchards would add substantially to the security of the genetic resource and these are being established at present with a total of over 2000 seedlings derived from the Calverts Hill population.

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