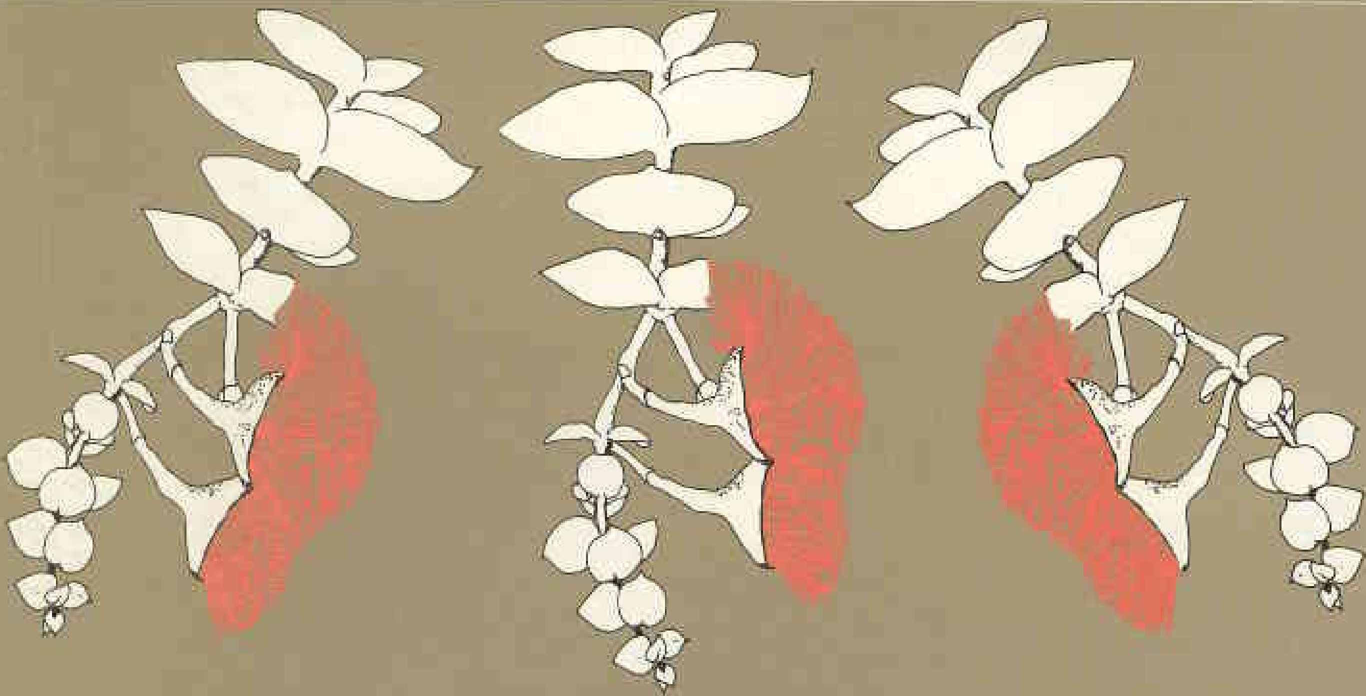
Eucalyptus Rhodantha

by J.F. Sampson, S.D. Hopper and D.J. Coates



1990

Wildlife Management Program No 4

Department of Conservation and Land Management

WESTERN AUSTRALIAN WILDLIFE MANAGEMENT PROGRAM NO. 4

EUCALYPTUS RHODANTHA

by

J. F. Sampson, S. D. Hopper and D. J. Coates

Department of Conservation and Land Management
Western Australian Wildlife Research Centre
P. O. Box 51, Wanneroo, W. A. 6065

1989

Department of Conservation and Land Management,
P. O. Box 104, Como, W. A. 6152

ISSN 0816-9713

FOREWORD

Western Australian Wildlife Management Programs are a series of publications produced by the Department of Conservation and Land Management. The programs are prepared in addition to Regional Management Plans to provide detailed information and guidance for the management and protection of certain exploited or rare and endangered species (e. g., Kangaroos, Noisy Scrub-bird).

This program is the fourth in the series and is concerned with the one species of rare flora, *Eucalyptus rhodantha* Blakely & Steedman. It provides a brief description of the available research on the species, a discussion of the general approach for its conservation and detailed management actions to ensure and enhance the survival of *E. rhodantha*.

ACKNOWLEDGEMENTS

We thank the Scott family for allowing access to their property and for their invaluable contribution to the conservation of *E. rhodantha*.

The Western Australian Bushfires Board and staff of the Moora office of the Department of CALM provided the equipment and expertise for a controlled burn. We gratefully acknowledge their assistance.

We thank Shapelle McNee for her comments and advice and for access to unpublished results.

SUMMARY

Eucalyptus rhodantha Blakely & Steedman is one of Western Australia's most rare and endangered plant species. There are only a few small remnants of this species left in agricultural areas, inbreeding has increased significantly in the small, isolated stands and recruitment of seedlings has not been observed. The species is therefore threatened with extinction. Research conducted by the University of Western Australia and Curtin University in association with the Department of CALM forms a basis upon which rational strategies for the conservation and management of this unusual bird-pollinated eucalypt may be based. Investigations indicate that the largest remnant on uncleared land is the highest priority for conservation but that smaller remnants should be rehabilitated to ensure and enhance the survival of the species.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Eucalyptus is the most notable and distinctive tree genus of the Australian flora. There are over 500 species and subspecific taxa confined almost entirely to Australia and the genus has great economic, scientific and aesthetic importance (Pryor 1981; Chippendale 1988). Furthermore, because eucalypts are such a dominant element of the flora, the fate of many associated plant and animal species depends on that of eucalypts. The genus therefore merits the attention of both those aiming to conserve the diversity of natural systems or the viability of agricultural systems, and those whose concern is the preservation of economically useful genetic resources.

Eucalyptus rhodantha Blakely & Steedman, the rose mallee, merits special attention for several reasons. Firstly, there are less than 500 plants in existence so it is one of Western Australia's most rare and endangered species (Lucas and Synge 1978; Pryor 1981; Rye and Hopper 1981). Secondly, the remaining plants occupy soils and situations where their continued survival is uncertain and finally, the survival of this striking species is also threatened by a decline in outbreeding in small isolated stands and by a lack of natural recruitment (Sampson 1988).

Ideally, species would be preserved within ecosystems in vast reserves, but this is often not possible. The agricultural wheatbelt area of south Western Australia was essentially virgin land at the turn of the century but is now virtually completely settled (Main 1987). During the early settlement phases there was no policy of setting aside areas for conservation of flora and fauna so the loss of vegetation in this area has been considerable. Species such as *E. rhodantha* have been reduced to remnant stands in a matrix of agricultural land use.

E. rhodantha has been gazetted as rare and endangered flora and is therefore protected under the Western Australian Wildlife Conservation Act 1950-1979. However, the species clearly requires management to ensure its long term survival. To be effective, conservation and management of species in small reserves and rehabilitation or founding of new populations should be based on genetic and ecological principles.

Recently, detailed research into the genetic systems and reproductive biology of *E. rhodantha* has been conducted by The University of Western Australia and Curtin University in co-operation with the Department of CALM. These investigations, together with ecological principles, form a basis for the development of rational strategies for the conservation and management of *E. rhodantha*.

2. BACKGROUND

2.1. Description and Taxonomy

E. rhodantha is a low spreading mallee which grows up to 3 m in height, with smooth, grey-brown bark and white-grey branches. It is distinguished by its grey-blue, highly glaucous leaves which are typically thick, opposite and decussate (Fig. 2.1 A). Leaves are orbicular-cordate, pointed at the top, 6-8 cm in length and about the same in width. There is usually one, but may be up to 3, flower buds in the umbel which is attached by a thick grey stalk (Fig. 2.1 B). Each grey bud may be up to 5.5 cm long and 4 cm wide. The cap is typically conical, longer than the base and attached by a stalk up to 4 cm long. Flowers may be up to 7.5 cm across and usually have red filaments with yellow anthers although there is a form with pale yellow to pink filaments (Fig. 2.1 C). The fruit is more or less hemispherical, woody and up to 3 cm by 5 cm, with protruding triangular valves containing brown to dark brown winged seeds (Fig. 2.1 D and E). *E. rhodantha* may be distinguished from the similar species, *Eucalyptus macrocarpa* Hook., by its smaller leaves and stalked flowers.

Considerable variation in form has been reported in *E. rhodantha* and this has contributed to argument about its systematic status and relationships. It was named from material collected near Gunyidi by H. Steedman in 1934 (Blakely *et al.* 1938). It is now included, along with *E. macrocarpa* and *Eucalyptus lane-poolei* Maiden, in the informal series *Macrocarpae* and subseries *Macrocarpinae* .

A form with cordate-lanceolate leaves and a short, flat petiole was described as var. *petiolaris* Blakely & Steedman (Blakely *et al.* 1938; Fig. 2.2). Gardner (1961) recognised this variety and regarded *E. rhodantha* as a variable but distinct species. Chippendale (1973), however, considered that all forms of *E. rhodantha* belonged to one species. *E. rhodantha* was not included in Pryor and Johnson's (1971) classification of the eucalypts since they considered it to be a hybrid of *E. macrocarpa* x *Eucalyptus pyriformis* Turcz. This interpretation was based on confusion between *E. rhodantha* and real *E. macrocarpa* x *E. pyriformis* hybrids. Later, research established that *E. rhodantha* is not a hybrid and led to it being gazetted as rare and endangered flora (Rye and Hopper 1981). *E. rhodantha* is now regarded as a highly restricted species, distinct from other eucalypts but having some relationship with *E. macrocarpa* and *E. pyriformis* (Pryor 1981).

2.2. Distribution and Habitat

The present distribution *E. rhodantha* is known only from remnant stands since, in most of the area the original vegetation has been cleared for agriculture. Gardner (1961) reported that it extended

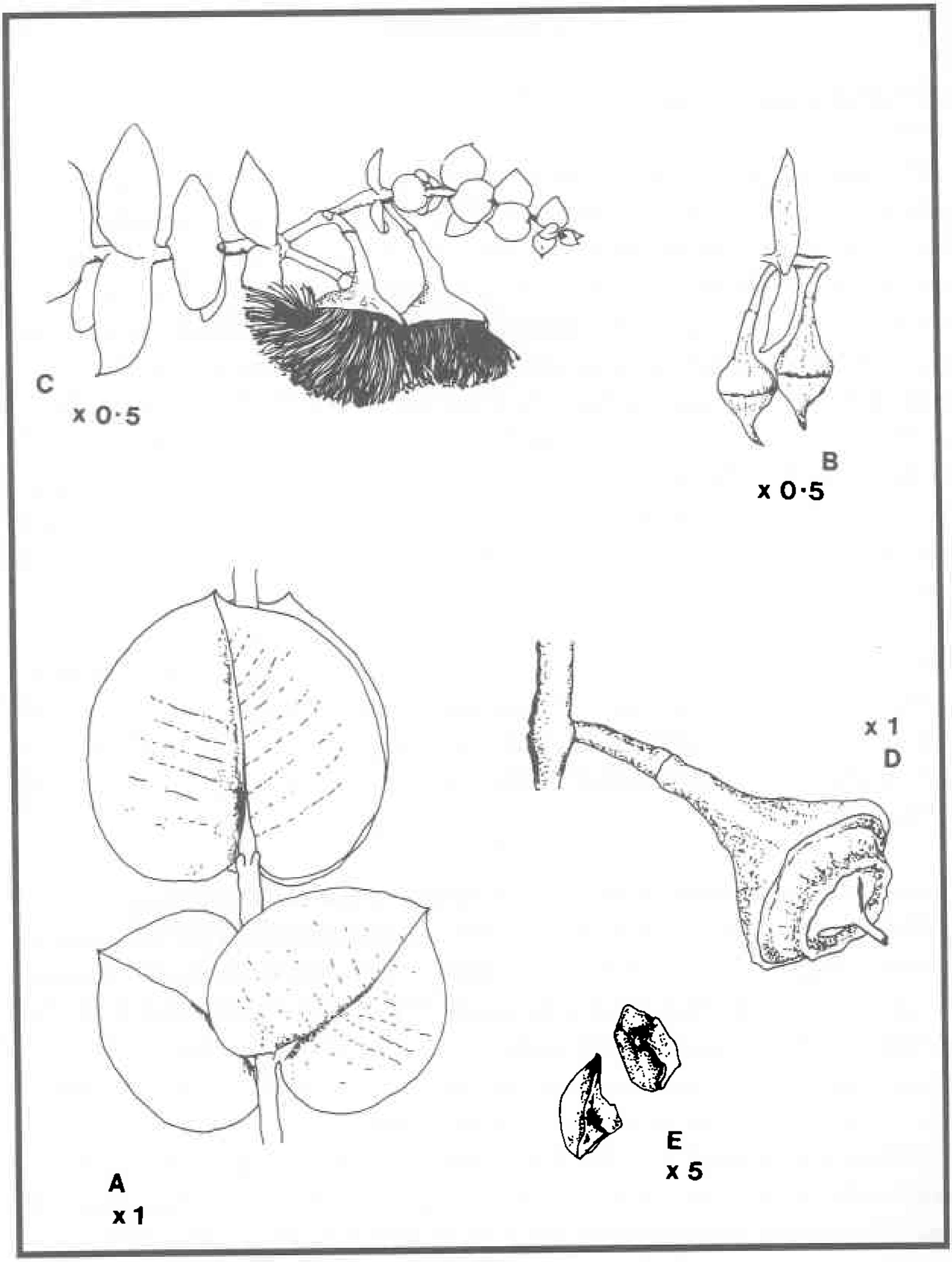


Figure 2.1 Diagrams of the distinctive floral and vegetative structures of *E. rhodantha* var. *rhodantha*

A, leaves; B, buds; C, flowers; D, fruit; E, seeds [from Gardner (1961)].

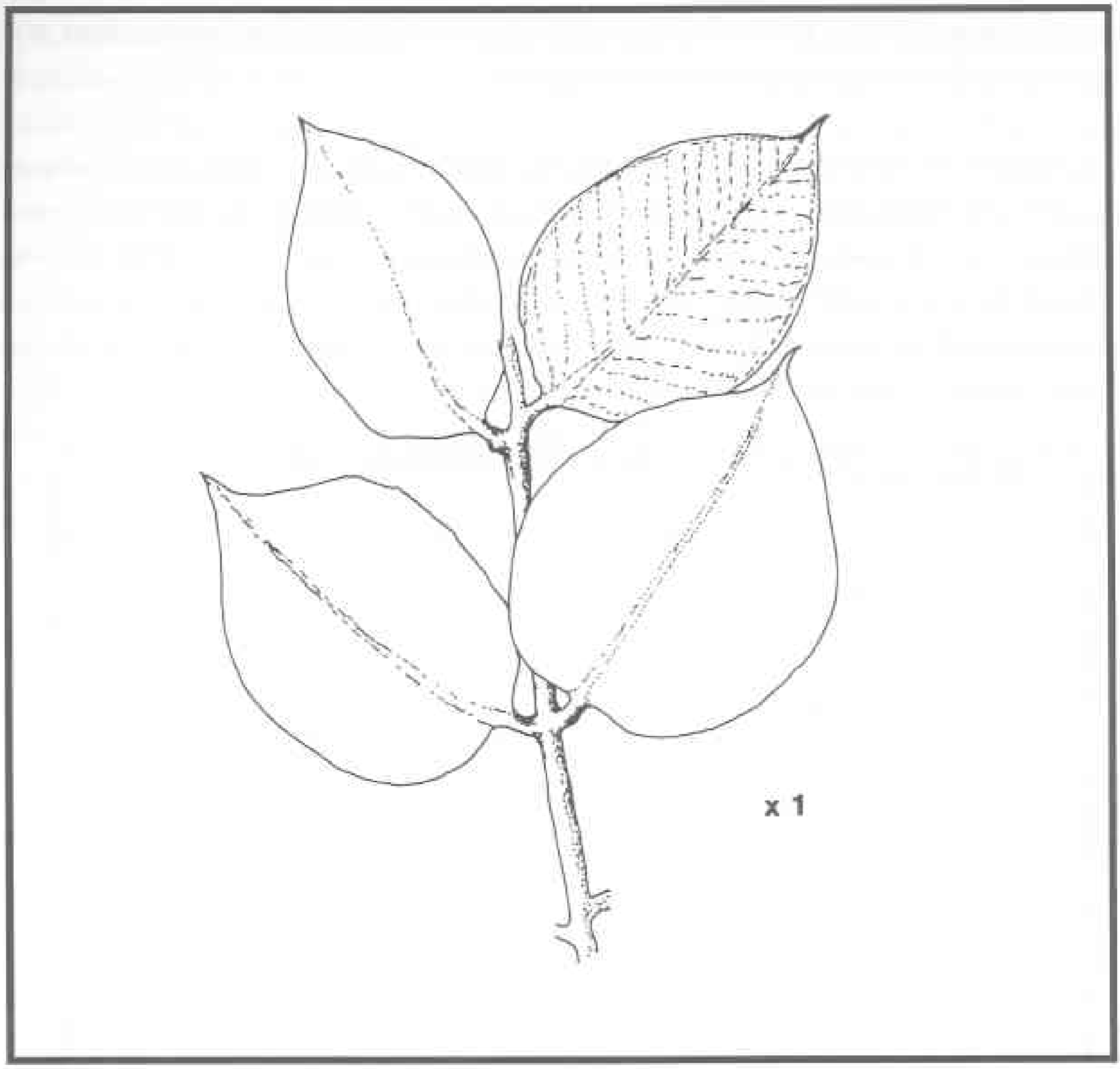


Figure 2.2 Diagram of the distinctive leaves of *E. rhodantha* var. *petiolaris*

from Hill River (where it was mixed with *E. macrocarpa*) to Gunyidi, some miles eastward from Watheroo and southwards to near New Norcia. This pattern may not be accurate since the herbarium specimens do not support it (S. D. Hopper personal communication).

Inferences about the size and distribution of its populations may be drawn from comparisons with its close relative *E. macrocarpa* which, although more widespread, occupies similar soils. The distribution of E. *macrocarpa* has also been affected by land clearance but the number of surviving population exceeds that of *E. rhodantha* and there are historical records of its distribution (Anon. 1981). Populations of *E. macrocarpa* range from isolated individuals to hundreds of plants covering tens of hectares, but the majority of populations cover only a couple of hectares (S. D. Hopper personal communication). Prior to European settlement, *E. rhodantha* probably also consisted of a narrow belt of discontinuous populations of varying sizes.

E. rhodantha var. *rhodantha* is now confined to two areas between Three Springs and Watheroo (Fig. 2.3). All stands occur within the Department of CALM Greenough Management Region. Locations of and estimated sizes of remnant stands of *E. rhodantha* are given in Table 2.1. The climate of the area is 'extra-dry mediterranean' (Beard 1984) with an average of 80 days rain, the majority of which occurs during May to August. The mean annual rainfall at Watheroo is 428 mm (Western Australian Bureau of Meteorology).

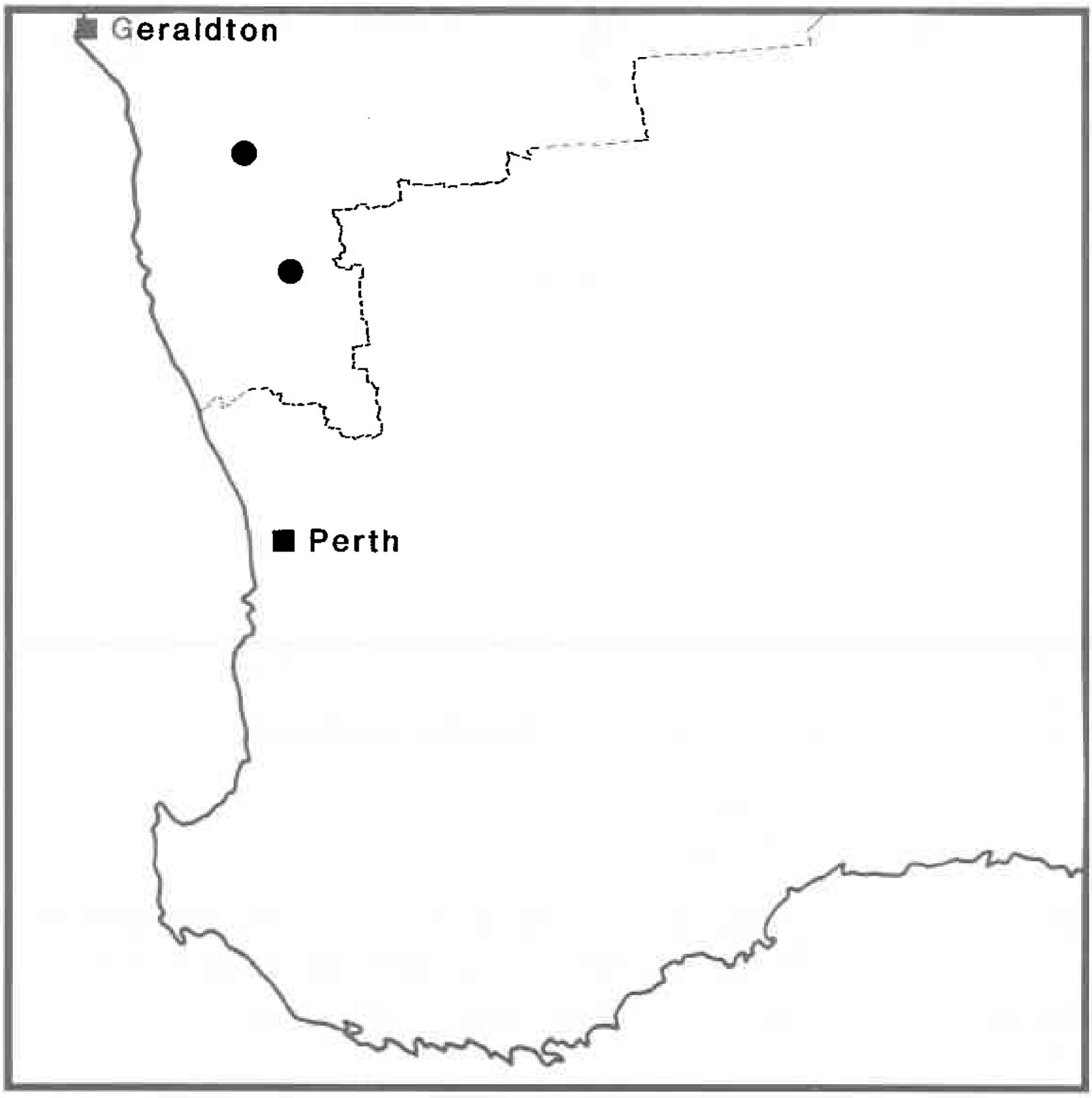


Figure 2.3 Geographical distribution of remnant stands of *E. rhodantha* in south-western Australia

Occurs only within the Department of CALM Greenough Management Region (----).

E. rhodantha var. *rhodantha* grows on grey sandy soil in flat or slightly undulating country. Plants now occur on roadsides and scattered in paddocks. There are two northern stands occurring within 1 km of each other and 5 southern stands distributed within an area of about 15 square km. Only two of the southern stands (4 and 5) are on uncleared land. These occur as almost pure communities with some low heath vegetation including *Allocasuarina campestris* Diels, *Dryandra ashbeyi* B. L. Burtt., *Calothamnus quadrifidus* R. Br., *Gastrolobium spinosum* Benth., *Podolepus capillaris* (Steetz) Diels, *Hakea trifurcata* (Sm.) R. Br., *Hakea sulcata* R. Br., *Grevillea eriostachya* Lindley, *Danthonia* sp. and *Acacia* sp. There are adjacent stands of *Banksia prionotes* Lindl. and *Eucalyptus loxophleba* Benth. Approximately 8 ha of one uncleared stand is completely fenced off from the surrounding agricultural land. Stand 3 consists of 14 mallees grouped together (stand 3a), some on a road verge and some on partially cleared land along a creekline. The remaining 23 plants are scattered over about 25 ha in a paddock (Fig. 2.4).

Table 2.1 Locations and estimated sizes of remnant stands of E. *rhodantha*

* Road verge. ᐃ Private property. See map in Fig. 2.3.

Stand number	Stand name	Estimated No. of *E. rhodantha*
E. rhodantha var. *rhodantha*		
1*	north west	14
2*	north east	8
3ᐃ	paddock	37
3aᐃ	creekline (subpopulation of 3)	14
4ᐃ	west main	180
5ᐃ	east main	150
6*	road	9
7ᐃ	south	6
8ᐃ	fenceline	1
E. rhodantha var. *petiolaris*		
1ᐃ	north west	1
2ᐃ	north east	1
9ᐃ	north	1
3*	paddock	1
3*	paddock	1
5ᐃ	east main	1

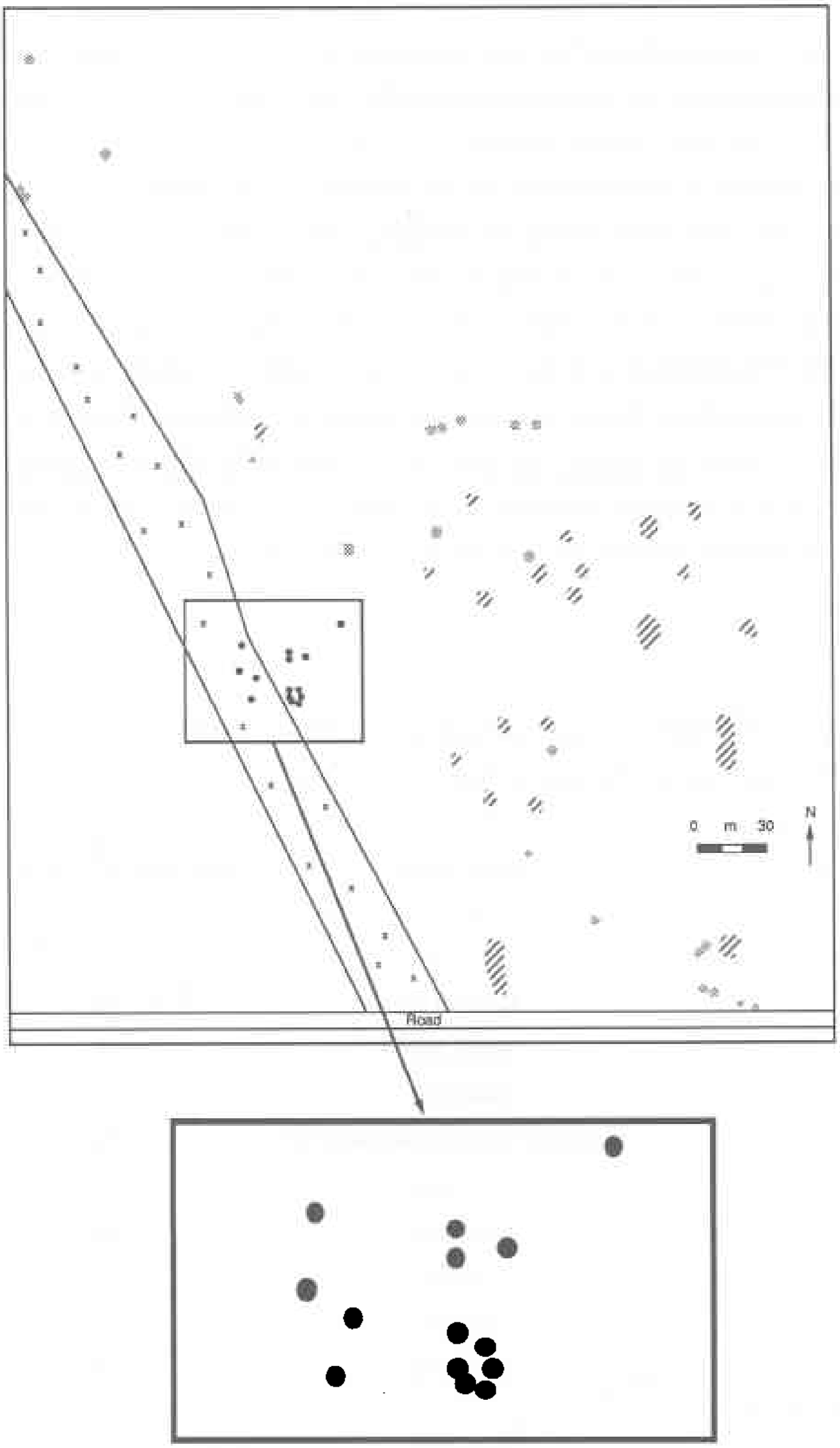


Figure 2.4 Diagrammatic representation of Stand 3 showing the distribution of *E. rhodantha* and the location of subpopulation 3a

(•) Stand 3a mallee, (⊛) Other *E. rhodantha* , (⫽) Other species, mainly *Eucalyptus todtiana* F. Muell. (—) Fence. (ˣ) Uncleared land along creekline. The scale is approximate.

E. rhodantha var. *petiolaris* is known only from two areas, one near Watheroo and the other near Three Springs. It occurs on flat or slightly undulating country in sandy soil, sometimes in association with *E. rhodantha* var. *rhodantha*. It is unlikely that more stands will be found since the area is extensively farmed.

2.3. Biology

E. rhodantha flowers between March and November but the peak flowering times range between the winter months of June to August depending on the site (Fig. 2.5; McNee 1986; Sampson 1988). The species is unusual amongst eucalypts in that it usually produces very few (1-56) open flowers on each plant even at peak flowering. However, up to 208 flowers have been recorded on a single plant in an exceptional flowering season. The total number of flowers produced in a season can vary significantly between years. For example, 500 flowers were recorded at peak flowering in the west main stand in 1986. In the same stand in 1988, there were 3000 flowers.

Individual plants differ considerably in the total number of flowers they produce and in the time of onset and the duration of flowering. In a survey of 25 plants in 1986, one plant contributed 20.42 per cent of the open flowers recorded over the entire season whilst eight plants contributed less than 1 per cent each. Cross-pollination between some plants was impossible because their flowering seasons did not coincide.

Vegetative growth and the development of buds occurs during the summer months. Predation by *Haplonyx maximus* (*E. rhodantha* bud weevil) and the parrot, *Barnardius zonarius*, reduces the number of buds which eventually flower (McNee 1986). Flowers are long-lived (20-30 days) and produce copious amounts of nectar, mainly during the day. This nectar is harvested by several species including the honeyeater bird species *Lichmera indistincta, Lichenostomus virescens, Manorina flavigula* and *Anthochaera carunculata* and the parrot *B. zonarius*. From point census counts at the west main site maximum numbers observed for honeyeaters were 30 *L. indistincta*, 21 *L. virescens* and 21 *M. flavigula* in 1986 (McNee personal communication).

Insects also harvest nectar. Species include the ant *Prolasius 'pallidus'*, other *Prolasius* spp., *Apis mellifera, Iridomyrmex* spp., native bees and several moths and butterflies. Another honeyeater, *Phylidonyris albifrons*, has also been observed in *E. rhodantha* stands but has not been observed foraging. *E. rhodantha* pollen has, however, been found in pollen smears from this species. *Tarsipes rostratus* (honey-possum) and *Sminthopsis* (dunart) have been observed in Stand 4 as well as *Mus musculus* (house mouse), kangaroos and rabbits. Evidence suggests that the honey-possum may harvest pollen from *E. rhodantha* flowers.

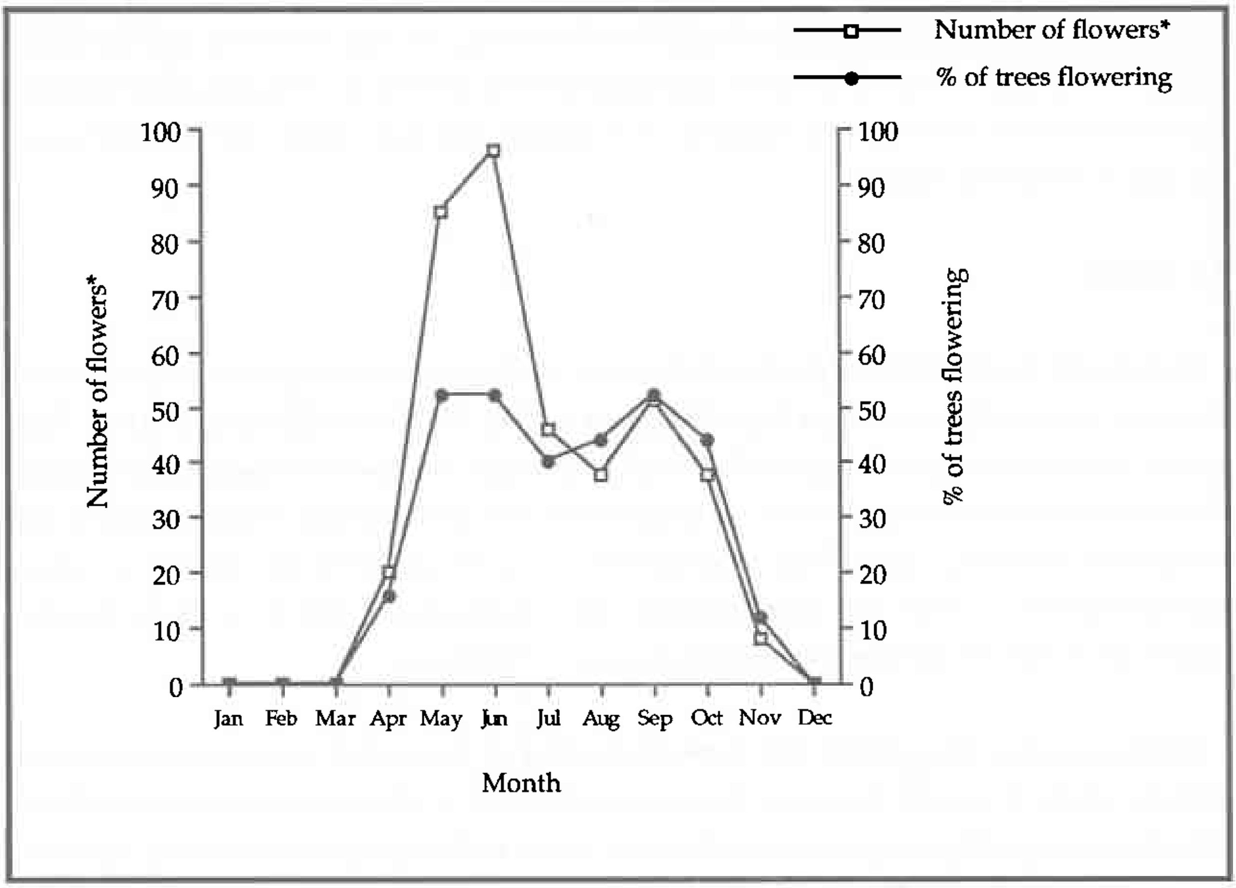


Figure 2.5 Estimated number of flowers releasing pollen and proportion of plants releasing pollen in a sample of 25 plants in Stand 4 during 1986

*, open flowers with intact staminal rings. After Sampson (1988).

L. virescens and *M. flavigula* are thought to be the main pollinators of *E. rhodantha* (McNee 1986). These species have been observed nesting in the west main stand, but the nests were not in *E. rhodantha* plants which are very open and provide limited protection. Bird species do not forage on *E. rhodantha* exclusively but use a variety of flowering species which occur locally, including *B. prionotes, D. ashbyi, G. eriostachya* and *C. quadrifidus*. The species being exploited alters throughout the year. Some types of bird may forage primarily on plant species which flower concurrently with *E. rhodantha.*

2.3.1. The breeding system

The flowering strategy of *E. rhodantha* and observations of bird behaviour suggest that it is pollinated primarily by birds, mainly *M. flavigula* and *L. virescens*. Flowers are large and produce copious quantities of nectar. They are pendulous and the stamen filaments are conspicuously red. These features characterise many bird-pollinated plant species (Ford *et al.* 1979).

Flowers of *E. rhodantha* are protandrous. Most of the pollen is shed from the anthers within six or seven days after anthesis while the stigma does not become receptive until about 12 days after anthesis (McNee 1986). Protandry is generally thought to be a mechanism to reduce or prevent self-pollination but self-pollination is not prevented in *E. rhodantha* since several flowers at different stages of development may be open on a plant at any one time. Furthermore, single plants in isolated locations can set seed which suggests that they are not self-incompatible and that self-pollination does occur in this species.

Hopper and Moran (1981) suggested that the evolution of bird pollination in eucalypts may represent the evolution of a system to promote outcrossing and hybridity. These authors suggested that bird pollination may provide a mechanism whereby the deleterious consequences of inbreeding are reduced in small dissected populations which characterise *E. rhodantha* and most of the other large-flowered vertebrate-pollinated Western Australian eucalypts.

The mating system of *E. rhodantha* has been investigated in detail using isozyme markers and maximum-likelihood estimation procedures (Sampson 1988; Sampson *et al.* 1990). These procedures provide an estimate of the 'effective' outcrossing rate ($\hat{t}$) which can range between 0 (complete selfing) and 1 (complete outcrossing). The estimate of outcrossing rate in a relatively undisturbed stand of *E. rhodantha* was 0.59 and, together with other investigations, suggested that *E. rhodantha* has a mixed mating system with predominant outcrossing but a significant proportion of self-pollination.

An outcrossing rate of 0.59 is at the low end of the range reported for other eucalypts (Table 2.2). However, the other species studied have been forest trees or mallees which occur in relatively large, dense populations. *E. rhodantha* maintains a substantial level of outcrossing for a self-compatible plant distributed as small isolated stands within which the distribution of individuals is patchy so that some plants may be isolated from their nearest neighbour by 90 m. Therefore, the level of outcrossing in natural stands of *E. rhodantha* and the distribution of genetic diversity support the hypothesis that bird-pollination in eucalypts may promote outcrossing and diversity.

Investigations also revealed that gene flow within stands may be limited and that the stands consist of several genetically different neighbourhoods. Some inbreeding other than self-pollination also occurs, probably as a result of matings between related plants within relatively small family neighbourhoods and between plants that flower at the same time.

Table 2.2 Estimates of the outcrossing rate ($\hat{t}$) in eleven eucalypt species

Species	$\hat{t}$	Source
***E. rhodantha* (undisturbed stand)**	**0.59**	**Sampson (1988)**
***E. rhodantha* (disturbed stand)**	**0.26**	**Sampson (1988)**
Eucalyptus obliqua L'Hérit	0.76	Brown *et al.* (1975)
Eucalyptus pauciflora Sieber ex. Spreng.	0.70	Phillips and Brown (1977)
Eucalyptus delegatensis R. T. Bak.	0.79	Moran and Brown (1980)
Eucalyptus regnans F. Muell.	0.69	Moran and Bell (1983)
Eucalyptus stellulata Sieber ex DC.	0.77	Moran and Bell (1983)
Eucalyptus stoatei C. A. Gardner	0.82	Hopper and Moran (1981)
Eucalyptus kitsoniana (Luehm.) Maiden	0.77	Fripp (1982)
Eucalyptus citriodora Hook.	0.86	Yeh *et al.* (1983)
Eucalyptus grandis Hill ex. Maiden	0.84	Moran and Bell (1983)
Eucalyptus saligna Sm.	0.77	Moran and Bell (1983)

An important factor which probably contributes to the maintenance of a mixed mating system in *E. rhodantha* is selection favouring heterozygous progeny which are more likely to be produced by outcrossing. The levels of heterozygosity observed in mature *E. rhodantha* plants were significantly higher than those detected in seeds or newly germinated seedlings. This suggests that selection is operating during the life cycle. Heterozygotes may be more likely to survive at all stages from fertilisation onward; through seed maturation, germination, early seedling growth and as the plant matures. Similar processes are thought to occur in several other eucalypts that have been investigated (Phillips and Brown 1977; Moran and Brown 1980; Hopper and Moran 1981; Fripp 1982; Sampson *et al.* 1988) and in other trees (Ledig 1986).

2.3.2. The distribution of genetic diversity within and between remnant stands

Reviews of the relationships between ecological and life history traits and the genetic structures of plant populations (Hamrick *et al.* 1979; Loveless and Hamrick 1984; Karron 1987) indicate that there may be some major determinants of the distribution of genetic diversity within and between populations. In particular, the importance of the breeding system in determining population structure is widely recognised (Jain 1975; Brown 1978, 1979; Hamrick *et al.* 1979; Gottlieb 1981; Hamrick 1983; Loveless and Hamrick 1984). In general, ecological and life history traits which promote outbreeding and gene flow are associated with higher levels of intrapopulational diversity and lower differentiation of populations.

The level and distribution of genetic diversity is affected by the distribution and size of populations. Theoretically, the fragmentation of species into small populations may lead to increased inbreeding within populations and a reduction in heterozygosity (Jain 1976) although the loss of heterozygosity may be small if population size increases rapidly after a bottleneck (Nei *et al.* 1975). The loss of alleles and reduction in the number of polymorphic loci are secondary responses to drift, selection and the constraints of gene flow.

Remnants of *E. rhodantha* range in size but the average levels of genetic diversity found in all of them were high. Mixed mating systems, selection favouring heterozygotes and longevity, associated with spatial and temporal heterogeneity and the accumulation of mutations, were suggested as factors contributing to the maintenance of diversity in these species. However, the effects of fragmentation and small population size were apparent. There were weak correlations between some measures of genetic diversity and population size and a significant increase in inbreeding was found in a small stand of isolated mallees (see Section 2.3.4.). *E. rhodantha* does have characteristics listed above which promote diversity but, it seems these may not be enough to overcome the impact of inbreeding, drift and reduced gene flow in the smaller remnants.

Estimates showing the distribution of diversity within and between stands of *E. rhodantha* and populations of several other eucalypts are given in Table 2.3. The differentiation between the remnant stands of *E. rhodantha* was significant but relatively low. This is the pattern observed in most tree species, including eucalypts (Ledig 1986; Moran and Hopper 1987). In *E. rhodantha,* it may be attributed to relatively high levels of gene flow between populations that, prior to clearing, were less isolated than the present day remnants.

Significant but low differentiation was also illustrated by genetic distance measures (Fig. 2.6). The mean estimate of genetic distance (D=0.061) was similar to that reported for populations of 21 other plant species (Gottlieb 1977). In general mean genetic distance increased with geographical distance as can be seen from the separation of Stands 1 and 2 from the southern stands. Caution should be exercised when interpreting relationships based on genetic distance in *E. rhodantha* since the sampling procedure and levels of diversity may have distorted the true pattern.

Genetic differentiation may also occur on a local scale within plant populations. In a review, Loveless and Hamrick (1984) found that the proportion between populations was approximately twice that between population subdivisions. Comparison of the distribution of genetic diversity within and between two arbitrary *E. rhodantha* subpopulations approximately 160 m apart (Fig. 2.7) indicated that they were significantly different, although the level of differentiation was low. As in other species, it was about half the level of the diversity between stands.

Table 2.3 Total genetic diversity and the distribution of diversity within and between populations of trees of widespread, regional and localised geographic distributions

H_T, total genetic diversity. H_S, mean genetic diversity within populations. D_{ST}, mean genetic diversity between populations. G_{ST}, mean proportion of diversity between populations.

Species	No. of populations	H_T	H_S	G_{ST} (%)	Source[a]
WIDESPREAD					
Pinus ponderosa Engelm.	11	0.289	0.284	1.5	1
Pinus radiata D. Don	5	0.117	0.098	16.2	2
E. grandis	12	0.190	0.167	12.0	3
E. saligna	7	0.260	0.239	8.0	3
Eucalyptus cloeziana F. Muell.	17	0.270	0.240	11.0	4
Casuarina cunninghamiana	20	0.292	0.208	28.7	2
REGIONAL					
Eucalyptus caesia Benth.	13	0.176	0.068	61.4	5
E. crucis	10	0.320	0.222	24.4	6
E. lane-poolei	7	0.324	0.272	13.7	7
Eucalyptus diversicolor F. Muell.	13	0.299	0.270	9.2	8
E. rhodantha	6	0.265	0.221	10.1	7
LOCALISED					
Eucalyptus lateritica Brooker & Hopper	2	0.318	0.278	12.6	2
Eucalyptus pendens Brooker	7	0.170	0.156	8.2	2
Eucalyptus johnsoniana Brooker & Hopper	3	0.139	0.084	39.6	2
Eucalyptus suberea Brooker & Hopper	3	0.197	0.170	13.7	2

[a]Sources of data: (1) Hamrick (1983), (2) Moran and Hopper (1987), (3) Burgess and Bell (1983), (4) Turnbull (1980), (5) Moran and Hopper (1987), (6) Sampson *et al.* (1988), (7) Sampson (1988), (8) Coates (personal communication).

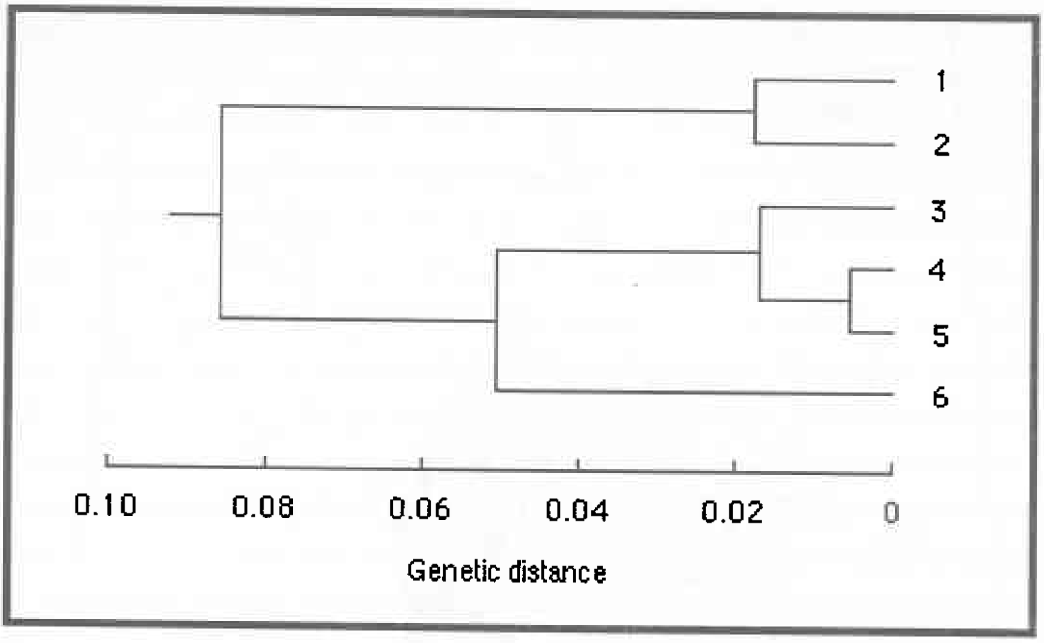


Figure 2.6 Dendrogram based on UPGMA cluster analysis of genetic distance measures (*D*; Nei 1978) showing the relationships between the remnant stands of *E. rhodantha*

See Table 2.1 for stand locations. After Sampson (1988).

2.3.3. Gene flow

Quantitative estimates of gene flow between and gene dispersal within natural populations are difficult to obtain. Direct measurements of gene flow in *E. rhodantha* have been obtained from observations of pollinator movements (McNee 1986) and by examining the dispersal patterns of distinctive alleles in sites 3 and 4 (Sampson 1988). Indirect estimates of gene flow have been made using the method of Slatkin (1985) and by estimating the amount of diversity between pollen pools (Sampson 1988).

The investigations of McNee (1986) illustrated that several bird species and the honey possum, *T. rostratus*, carry *E. rhodantha* pollen although *L. virescens* and *M. flavigula* were considered the most likely pollinators. *E. rhodantha* pollen may be transported over large distances by birds. Species that carried *E. rhodantha* pollen were observed feeding on flowers and collecting pollen and then flying up to 60 m to the next flower. In contrast, some species established territories and movements were concentrated between a few plants (McNee 1989). Birds also flew over uncleared bush between stands and some moved out of stands to unknown destinations for prolonged periods, providing opportunities for interpopulational gene flow. The number and behaviour of bird species

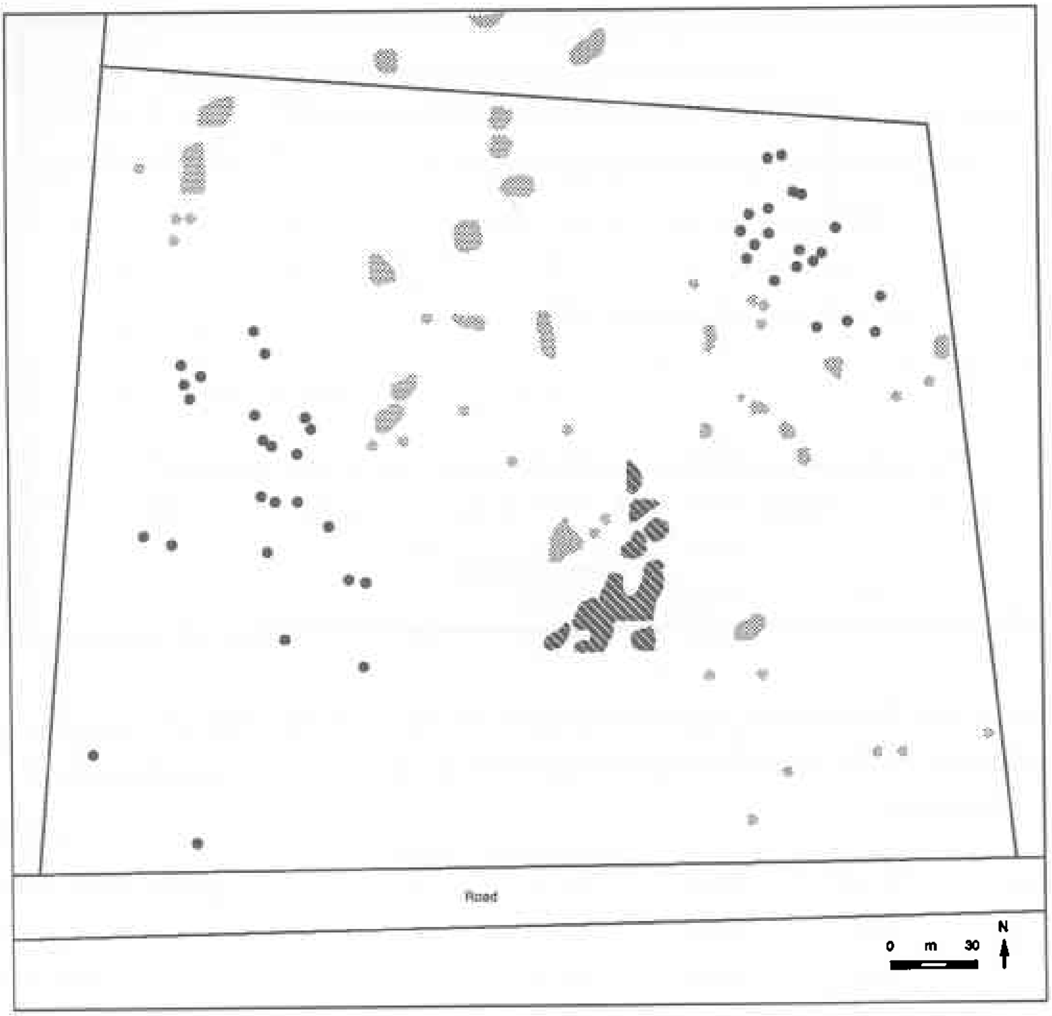


Figure 2.7 Diagrammatic representation of *E. rhodantha* at Stand 4 showing the position of subpopulations 1 (west) and 2 (east) and the area burnt in April 1986
(•) Sampled plant, (*), Other *E. rhodantha*. (▓), *E. rhodantha* burnt April 14th, 1986. (—), Fence. The scale is approximate.

found in stands varied between years, apparently because of the number of flowers and availability of nectar.

Seed morphology and observations of seed dispersal also suggest a potential for gene flow over relatively large distances. Seeds are winged and are blown readily through the patchy vegetation by strong prevailing winds.

Estimates of gene dispersal from the distribution of rare non-maternal alleles ranged between approximately 8 and 186 m (mean 67 m, s.e. 26.62). Comparison of adult plant and pollen pool gene frequencies between two arbitrary subpopulations in an uncleared stand (No. 4; Fig. 2.7) suggested that movement of pollen between the two subpopulations, only 160 m apart, was limited.

Slatkin (1985) developed a method of estimating gene flow as the mean number of migrants per generation. Estimates less than 1.0 indicate low gene flow, whereas estimates larger than 1.0 suggest high levels of gene flow. The method is far from precise but it provides an indicator since gene flow in natural populations may differ by two or more orders of magnitude and there is some consistency between taxa. The estimate of gene flow in *E. rhodantha* based upon this method was very high (Table 2.4). It was one or two orders of magnitude greater than interpopulational gene flow estimates made for three other regionally distributed species of eucalypts and larger than the size of present remnants but probably less than the size of some populations that are now extinct. High estimates may be obtained because values calculated by this method contain information more relevant to historical patterns of gene exchange than to the current population dynamics (Larson *et al.* 1984).

Investigations of gene flow within and between populations appear to give conflicting results. The evidence from surveys of genetic diversity and estimates of gene flow between populations in *E. rhodantha* suggest that gene flow between populations was high prior to clearing and an important species-wide cohesive force retarding the differentiation of populations. However, gene flow within populations is apparently limited. In a review, Loveless and Hamrick (1984) found that this pattern was not unusual in plants. It seems high gene flow between populations does not eliminate the possibility of within-population gene flow being restricted so that local neighbourhoods form and become genetically different as a result of genetic drift.

Table 2.4 Estimates of the mean number of migrants (*Nm*) exchanged between remnant stands of *E. rhodantha* and other species of regionally distributed eucalypts
$(Nm)_{est}$ = *Nm* corrected for sample size

Species	$(Nm)_{est}$
E. rhodantha	**> 10**
E. lane-poolei	2.38
E. crucis	0.54
E. caesia	0.95

After Sampson (1988).

2.3.4. Outcrossing rates in natural and disturbed stands

Outcrossing rates in plant populations are not fixed but are affected by several genetic and ecological factors including the size and density of populations and the availability and behaviour of pollinators. Theoretically a reduction in population size will be associated with an increase in inbreeding and reduction in fitness.

There was a substantial increase in inbreeding in *E. rhodantha* in a small remnant of 14 plants isolated in land cleared for agriculture (Stand 3a, Fig. 2.4; Sampson 1988). The level of outcrossing recorded in this stand ($\hat{t}=0.26$) was significantly lower than that determined for an uncleared stand and substantially lower than rates reported for any other eucalypt (see Table 2.2). It was attributed to a substantial increase in self-pollination, probably as a result of reduced plant and pollinators numbers.

The increase in inbreeding was not associated with a decrease in reproductive output as determined by the number of capsules produced per plant in one season, but these investigations were very limited. Observations suggest that the small remnants of *E. rhodantha* are less fecund than the larger populations and the plants appear less vigorous. This may be simply the result of environmental degradation. Whether increased inbreeding is associated with decreased fitness in *E. rhodantha* is a subject that requires further investigation.

2.3.5. Fecundity

Plants in disturbed and relatively undisturbed stands maintained moderate levels of seed set (Table 2.5). The number of fruit set per year was low when compared with the majority of eucalypts which produce numerous, usually thousands, of small flowers and fruits. This reflects the different flowering strategy of *E. rhodantha* which produces a few large flowers with large nectaries in each flowering season. The number of flowers and hence the number of capsules may vary substantially between years.

There were significant differences between plants for the number of seeds per fruit and the mean height of seedlings at eight weeks (Table 2.6). When within-plant variation was taken into account, no significant differences were found between plants or between stands for any of the other characters assessed (Tables 2.5 and 2.6).

Table 2.5 Capsule and seed production of *E. rhodantha* plants at Stand 3 and in two subpopulations in Stand 4

See Table 2.1 and Fig. 2.7 for stand and subpopulation locations. [A] Counted in Dec. 1985. [B] Counted in Feb. 1987. Standard errors in parentheses. ns, not scored.

	Site 3	Site 4 subpopulation 1	Site 4 subpopulation 2
No. fruits set/plant for 1985[A]			
mean	16.7 (3.9)	ns	ns
range	0-81		
N	37		
No. fruits set/plant for 1986[B]			
mean	7.3 (1.5)	3.9 (1.8)	6.1 (1.9)
range	0-61	0-13	0-15
N	37	25	20
No. seeds/fruit			
mean	41.8 (3.8)	23.7 (3.4)	58.4 (4.5)
range	3-113	0-78	12-156
N	39	39	39

After Sampson (1988).

2.3.6. Recruitment and vegetative regeneration

Seedling recruitment is reported to be rare in mallee communities and to occur following disturbance, particularly fire (Holland 1969; Wellington and Noble 1985a). Several factors have been suggested to limit recruitment in unburnt and recently burnt populations of mallees including a lack of viable seeds, the effects of predators limiting the establishment of a soil seed bank, a lack of suitable germination conditions and the inability of new seedlings to establish (Wellington and Noble 1985b).

E. rhodantha fruit open and release seed in the absence of fire (McNee 1989). Observation of five

Table 2.6 Mean seed and seedling characteristics scored in the progeny of ten *E. rhodantha* plants from Stand 3 and from each of two subpopulations in Stand 4

Values shown are the means of two replicates. See Table 2.1 and Fig. 2.7 for stand and subpopulation locations.

	Germination at 7 days (%)	Final germination (%)	Seedling alive at 8 weeks (%)	Height at 8 weeks (mm)
Stand 3				
Mean	13.5	47	42.75	54.97
Range	0-27.5	30-77.7	30-77.7	36.7-68.7
Subpopulation 1, stand 4				
Mean	10.5	54.5	46.25	61.42
Range	2.5-35	17.5-80	15-62.5	55.0-76.0
Subpopulation 2, stand 4				
Mean	26	72.25	63	52.5
Range	0-47.5	57.5-82.5	50-72.5	36.1-66.2

After Sampson (1988).

plants indicated that more than half of the fruit on a plant could open during a single year, with the highest opening rates occurring between October and December. Despite this supply of seed, natural seedling recruitment has not been reported in *E. rhodantha*. A limited investigation of the effects of fire on seedling recruitment and vegetative regeneration was conducted by Sampson (1988). Following a moderate April burn, 29 of 30 plants began coppicing at the onset of the first growing season following the fire (November 1986) and some flowered during the 1988 season, two years after the fire (McNee personal communication). No significant damage to or loss of the new vegetative growth was observed. This was attributed to the exclusion of sheep since rabbits and kangaroos still had access to the area. New shoots on plants in paddocks where stock have been grazing are usually stripped of leaves.

The fire was not followed by seedling recruitment. A substantial quantity of seed held in the canopy (≈27 000 seeds) was released following the fire but only six seedlings were observed. None of these seedlings was alive in August 1987. Sampson (1988) suggested that seed predators such as ants were not satiated following the fire because only a small area was burnt. This led to the rapid depletion of the seed after the fire by predators and wind, and was probably the major factor limiting germination in the burnt stand of *E. rhodantha.*

The elimination of damage due to grazing by large vertebrates had no significant effect on the mortality of planted seedlings (*t*-test, $P>0.05$; Fig. 2.8). Damage that might have been attributable to large vertebrates, such as broken stems, was not observed. Minor insect damage was observed on a few seedlings. Quadrats were not weeded and the growth of weed species, mainly *Avena fatua* L., *Arctotheca calendula* L. and *Ursinia anthemoides* L., and several native species, mainly *Danthonia* spp., *G. spinosum* and *P. capillaris* , was abundant, but substantially greater within fenced quadrats. Limitation of the supply of soil moisture and nutrients probably contributed

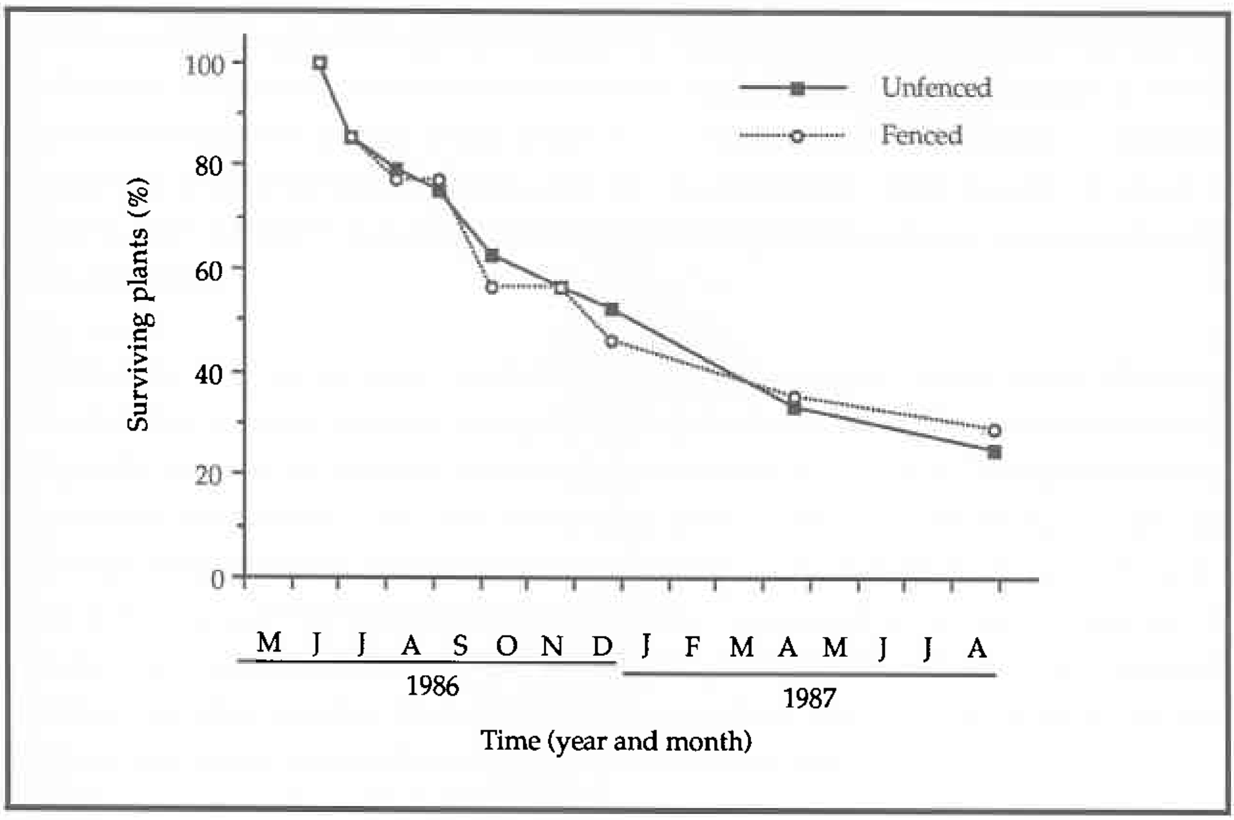


Figure 2.8 The mean percentage of *E. rhodantha* seedlings surviving in fenced enclosures compared with unfenced controls

The seedlings were planted in a burnt area of *E. rhodantha* during June 1986.

to the mortality of *E.rhodantha* seedlings planted in quadrats. It was unclear why there was no increase in the mortality over the summer period (December to February) when mean temperatures are high and rainfall negligible.

Seedling recruitment follows only a small proportion of fires in mallee eucalypt populations and occurs as a result of the coincidence of both fire and environmental conditions suitable for seedling establishment (Wellington and Noble 1985a). Observations in the small burnt site of *E. rhodantha* demonstrated that fire may have an important role in the reproductive biology of *E. rhodantha* by stimulating the release of large quantities of seed from the canopy. Similar suggestions have been made for many other sclerophyllous plants (Gill 1981). It seems reasonable to suggest that, prior to the clearing of vegetation, more extensive periodic fires in *E. rhodantha* populations may have stimulated the release of seed and satiated predators. When other conditions were suitable, recruitment would then occur.

3. MANAGEMENT

The objective of management is to ensure and enhance the continued survival in the wild of populations of *E. rhodantha*.

3.1. General strategy

The design of optimal strategies for the conservation and management of plant species requires an appreciation of the species' population genetic structure and morphological diversity. However, these considerations cannot be divorced from the ecological setting of plant populations. The provision and preservation of suitable habitats in conservation reserves is of prime importance (Soulé and Simberloff 1986).

Ledig (1986) concluded that the obvious management strategy for the conservation of outbreeding plants was to reduce inbreeding and to promote heterozygosity by maintaining population numbers, and enable gene flow among populations. The investigations of *E. rhodantha* described in the previous section support this general approach. The appropriate conservation strategy for *E. rhodantha* should then be to conserve diversity by maintaining population numbers at a level that will maintain the mating system found in undisturbed populations, prevent substantial increases in inbreeding and enable gene flow among populations. Thus, in order to conserve diversity, both the number and minimum viable effective size of populations to be conserved needs to be determined.

Estimation of minimum viable population sizes (MVP) is complex. In this report, MVPs are estimated from a genetic viewpoint to represent the size and structure of populations below which inbreeding and loss of variation would become a problem for survival. The two relatively undisturbed remnants of *E. rhodantha* (Stand 4, 180 plants and Stand 5, 150 plants) are probably above the minimum viable population size for this species, at least in the short term. However, since continuing gene flow from extant populations is no longer possible, the long term potential of this species is uncertain. The high level of inbreeding found in the small Stand 3a (14 plants) indicates this stand is below the minimum viable population size. Inbreeding levels are also probably high in the other small stands in cleared agricultural land.

The smallness of the remnants of *E. rhodantha* indicates they will require some management to prevent their degradation. Recovery of the original ecosystem may not be possible but rehabilitation or the restoration of certain desirable attributes to the surrounding agricultural land may be possible. Small isolated stands could be used as nuclei for the rehabilitation of populations. Clegg and Brown (1983) have described some of the genetic considerations and management options in the founding of plant populations. The information on the genetic diversity within and between stands and the mating system presented in this report provides a background on which decisions about founding and rehabilitation of populations may be based.

If *E. rhodantha* were still distributed as it was before European settlement, the appropriate conservation strategy would be to have several reserves containing entire populations scattered throughout the range of the species. This would conserve the range of morphological and genetic diversity, maintain levels of gene flow and cohesion in the species gene pool, and maintain habitats to conserve the flora and faunal diversity that contribute to community stability. This strategy can be modified and, with appropriate management, the remaining stands of *E. rhodantha* can provide a viable system of populations to ensure and enhance the survival of this rare flora.

Research has indicated that stands of *E. rhodantha* may be subdivided into genetically different neighbourhoods and that gene flow within populations is limited. When populations are subdivided in this way, it is important to preserve as much of the entire population as possible because the loss of a portion of it may be as critical in a genetic sense as loss of the entire population (Hamrick 1983). Therefore, entire populations of *E. rhodantha* should be conserved where possible and the larger, fecund populations should take priority (i. e., Stands 4 and 5, 1 and 2).

Recommendations for conservation should not be based solely on genetic data. Ideally they should include information from morphological and physiological studies (Hamrick 1983). Strategies to conserve *E. rhodantha* should therefore include both of its morphologically different varieties. The investigations of the response of *E. rhodantha* to fire and field observations provide limited but useful physiological information.

One approach which attempts to use genetic information to conserve variation is to maximise the conservation of locally-common alleles which are presumably maintained by selection. The pattern of distribution of this type of allele in *E. rhodantha* is artificial because its stands are remnants but all the existing locally-common alleles could be conserved by preserving Stands 1, 4 and 5. Another approach is to select populations on the basis of genetic distance. This is not advised for *E. rhodantha* since estimates of genetic distance for it may be biased and relationships unreliable.

3.2. Management actions

Kelly *et al.* (unpublished report) have described in detail the allocation of responsibility for rare flora within the Department of CALM. In general, the provision of advice on management prescriptions is the responsibility of Flora Conservation Research Program staff and the management and protection of rare flora is the responsibility of the regional officers. The acquisition of land is the responsibility of the Conservation Lands Acquisition Committee.

Precise locality details of known populations of *E. rhodantha* should be maintained on lists of Confidential Rare Flora in Regional and District offices. The register should be updated as required. If new populations are located, it is the responsibility of Wildlife and Land Administration personnel to determine the land's status and prepare material for notification of landowners. Hand-delivered notification of landowners of Declared Rare Flora populations is the responsibility of Regional Wildlife Protection Branch and Wildlife and Land Administration staff.

3.2.1. Liaison with landowners and Shires

Until now the conservation of *E. rhodantha* has been achieved largely through the foresight, goodwill and assistance of private landowners, shires and the Main Roads Department (MRD). It is both desirable and essential that this should continue. All management actions should be undertaken with the co-operation of landowners, shires and MRD staff.

When possible, conservation of *E. rhodantha* should be integrated with other projects that are of benefit to the landowner, shire and MRD. These could include prevention of soil erosion and salinity, the provision of shelter belts for stock and the control of insect pests.

3.2.2. Land acquisition

There are no specimens of *E. rhodantha* on land which has been reserved for the conservation of flora and fauna and only two stands remain on uncleared land. It is highly desirable that the Department should acquire land on which *E. rhodantha* occurs, either by donation, exchange or purchase. Since there are so few remnants, the ideal strategy would be to conserve all remnants. If this is not possible then priority should be determined by:

(a) the size and quality of the remnant and its habitat,
(b) conserving the range of genetic and morphological diversity and locally-common alleles,
(c) the likelihood of new populations being established around the existing remnant, and
(d) reducing the risk of sudden extinction.

The following is a listing of stands in order of priority for acquisition:

(a) Stands 4 and 5 (private)
(b) Stands 1 and 2 (Shire of Three Springs)
(c) Stand 3a (private)

(d) Stand 3 (entire stand, private)
(e) Stand 6 (Shire of Moora)
(f) Stand 7 (private)

Investigations suggest that about 25 plants spread over about 4 ha of natural habitat is above the effective population size for *E. rhodantha* (Sampson 1988). However, although most pollen dispersal may occur within neighbourhoods, neighbourhoods are not isolated. Gene flow within and between stands is an important component of the genetic system. Therefore, a minimum viable population should consist of more than one neighbourhood (subpopulation) of about 25 plants.

It is very important to maintain populations of pollinators. Birds forage on a variety of species and need species other than *E. rhodantha* for nesting. To ensure and enhance the survival of *E. rhodantha*, it is essential to provide and maintain areas containing a suitable variety of species and habitats.

Therefore, 35 ha is the minimum recommended reserve area for viable populations of *E. rhodantha*. There are two remnant stands in uncleared areas greater than this size (Stands 4 and 5) and they are the highest priority for conservation. Smaller remnants in suitable habitat may still be useful as long as they are above the estimated effective population size of 25 plants. These stands may fulfil the requirement of ensuring and enhancing the survival of *E. rhodantha* over the short term, but their value for long-term conservation is reduced.

3.2.3. Protection from grazing

Plants that are to be conserved require protection from grazing. This may be achieved either by fencing or by agreement with landowners to exclude stock. Evidence suggests that it is not necessary to exclude rabbits to protect *E. rhodantha* from grazing, however, the rabbit population should be controlled to prevent damage to the habitat. Part of Stand 4 has been adequately fenced by the landowner. Complete fencing of Stands 4 and 5 and the associated habitat should be the highest priority. This may conflict with the landowners requirements for grazing and shelter belts for stock. It is therefore essential that management actions include discussion with the landowners about the position of fences and provision of alternative shelter belts.

3.2.4. Protection from accidental destruction

Stands of *E. rhodantha* should be protected from accidental destruction or damage by bulldozing, off-road vehicles, rubbish dumping, spraying of potentially damaging herbicides and recreational land use.

Mining in areas adjacent to or within stands should be prevented or terminated and the land rehabilitated. The gravel pit north of Stand 2 is the highest priority for closure and rehabilitation (see Section 3.2.9.).

3.2.5. Protection from fire

The use of fire as a management tool for the promotion of seedling recruitment or vegetative regeneration of *E. rhodantha* is not recommended. *E. rhodantha* should be excluded from prescribed burns and protected from uncontrolled fires by construction of firebreaks or fuel reduction in surrounding areas.

3.2.6. Weed control

The control of weeds in or near stands that are to be preserved for conservation of *E. rhodantha* is desirable. Most stands are in agricultural land and are therefore surrounded by weeds. Officers of the department should liaise with Department of CALM staff with expertise in the area, the Agriculture Protection Board , MRD and private landowners.

Weeds should be removed by hand with minimum soil disturbance where use of selective herbicides may damage *E. rhodantha* or other native species. Department of CALM Information Sheets Nos. 1-87 and 2-88 provide information on the control of weeds in natural and direct seeded regeneration areas.

3.2.7. Linear marking

Stands 1, 2, 3 and 6 and some isolated specimens are located on roads and are subject to damage by maintenance operations. Linear marking would provide a minimum protection for these plants. Plants along firebreaks also need marking. The MRD has developed a field marking system for demarcating environmentally significant areas on road reserves. Local Shires have been encouraged to adopt this system (Kelly *et al.* unpublished report).

3.2.8. *Ex situ* conservation

Ex situ conservation is advisable for *E. rhodantha* to reduce the possibility of sudden extinctions through catastrophes such as fires or disease. It may be achieved through cultivation and long-term seed storage.

Seed from cultivated plants could be supplied to nurseries since the species has ornamental value. This may have the added benefit of reducing pressure on natural populations from illegal seed harvesters.

Seed from artificial plantations should not be used to re-establish or found new populations unless seed from wild populations is not available.

Seed from wild populations should be collected and placed in long term storage both as a precaution against sudden extinction and to conserve potentially important economic genetic materials. This seed should be representative of the range of genetic and morphological diversity and sampling should include populations with locally-common alleles (Stands 1, 4 and 5). In practice, all stands of *E. rhodantha* can be sampled with little effort. Within stands, sampling should be random. Information about the status of seed collections should be made available to field officers to ensure samples are representative and to prevent unnecessary re-sampling.

3.2.9. Rehabilitation of existing stands

Rehabilitation of the smaller existing stands is required to fulfil the objective of management. It should be done in co-operation with landowners, Shires and the MRD. Officers are referred to the Department of CALM Information Sheets Nos. 5-87 and 2-88, and Edmiston (1987) for advice on methods of rehabilitation.

The number of *E. rhodantha* plants in smaller stands that are to be conserved should be increased to at least 25. Re-establishment of other species, particularly those exploited by pollinators, is also essential. Ideally, artificial populations formed around the nuclei of remnant stands should form subpopulations of related individuals and levels of genetic diversity should be maintained. Seeds for re-planting should therefore come from existing plants. This may produce a founder effect so that the new population is not representative of the original population but complete elimination of genetic variation is rare even when the number of founders is small. If sufficient seed is not available from the stand being rehabilitated, then it should be obtained from the nearest population.

E. rhodantha seed germinates easily with the addition of water. Approximately 30 per cent of 6-week-old seedlings planted into the field in June were surviving 16 months later. Improved survivorship may be obtained by planting older seedlings with deeper root systems or by watering seedlings throughout the first summer. Investigations indicate herbivory by rabbits, kangaroos or insects is not a significant cause of seedling mortality and therefore it is unlikely seedlings would need protection from these factors.

The gravel pit area north of Stand 2 is the highest priority area for rehabilitation. Stands 1 and 2 should form the nucleus of a restored population in this area. Stand 3a is the next highest priority for rehabilitation.

3.2.10. Establishing new populations

If suitable habitats are available, *E. rhodantha* should be considered for establishment in less vulnerable areas or on land designated for nature conservation within the Three Springs-Moora area. New stands established for conservation of *E. rhodantha* should consist of at least 25 *E. rhodantha* mallees. It is also very important to include other plant species found in natural stands, especially those exploited by birds (e. g., *B. prionotes, D. ashbyi, C. quadrifidus, H. sulcata* and *G. eriostachys*). To simulate natural stands, seed for these plants should come from a restricted source area. A similar approach should be recommended to landowners who wish to establish new stands of *E. rhodantha* on their properties.

3.2.11. Artificial gene flow

Artificial gene flow between remnant stands is not recommended. Manipulation of gene flow may have destabilising and destructive effects (James 1982) and is not advised in the absence of information of the viability of interpopulational hybrids. The aim of this plan is to maintain and re-establish natural levels of gene flow by conserving and rehabilitating populations.

3.2.12. Monitoring

Ehrlich and Murphy (1987) and Hopkins *et al.* (1987), among others, have outlined the value of monitoring in remnants. The establishment and regular monitoring of sites within *E. rhodantha* stands may provide useful information on changes that occur in them and on the effectiveness of management actions that are undertaken. Fenced and unfenced quadrats of planted seedlings were established in Stand 4 in 1986 and monitoring of these should continue.

3.2.13 Dieback

Phytophthora cinnamomi and other pathogenic species *Phytophthora megasperma* var. *megasperma*, *Phytophthora megasperma* var. *sojae*, *Phytophthora citricola* and *Phytophthora drechsleri* have been isolated from several sites in the Greenough region. There is no research information available on the impact of these soil borne pathogens on *E. rhodantha* but they are known to kill species which support pollinators whose presence is essential to the survival of *E. rhodantha* (e. g., *Banksia prionotes*, McCredie *et al.* 1985).

Information on the locations of *Phytophthora* infections should be regularly updated and the management actions required to prevent the infection of *E. rhodantha* conservation areas should remain under revision. It is essential that *P. cinnamomi* and other pathogenic *Phytophthora* species be excluded not only from areas in which *E. rhodantha* occurs but also from the surrounding communities which contribute to the support of pollinators.

Guidelines for dieback hygiene procedures can be obtained from the Regional Office of CALM and the Moora District Dieback Protection Plan.

Table 3.1 Stands listed in order of priority for management actions
Priority determined on the basis of existing threat and benefit to the overall strategy. Refer to the text for details. *, Land acquisition is the responsibility of the Conservation Lands Acquisition Committee.

Management action	Stands in order of priority (first to last)					
1. Land acquisition*	4 and 5,	1 and 2,	3a,	3	6,	7
2. Protection from grazing	4 and 5,	rehabilitation stands				
3. Protection from accidental destruction	1 and 2,	3	6,	7,	4 and 5	
4. Protection from fire	4 and 5,	1 and 2,	3	6,	7	
5. Weed control	4 and 5,	rehabilitation stands,		remainder		
6. Linear marking	1 and 2,	6,	4 and 5, isolated roadside/firebreak plants			
7. *Ex situ* conservation	1, 4, and 5,	remainder				
8. Rehabilitation of existing stands	1 and 2,	3a,	3	6,	7,	4 and 5
9. Establishing new populations	not applicable					
10. Artificial gene flow	not applicable					
11. Monitoring	4 and 5,	1 and 2,	remainder			
12. Dieback	4 and 5, areas with *Banksia* and other susceptible species					

3.3. Term of the management program

This program shall run for a ten-year period, unless subsequent research or changes to the schedule of Declared Rare Flora cause it to be superseded earlier. During this period, the Department of CALM may institute any change to the provisions outlined in this program as are found, through further research, to be necessary for conservation of *E. rhodantha*.

REFERENCES

Anon. (1981). The Mottlecah, a plant in need of a place to grow. *Swans* **11,** 7-10.

Beard, J. S. (1984). Biogeography of the Kwongan. In *Kwongan, Plant Life of the Sandplain.* (Eds J. S. Pate, and J. S. Beard.) pp. 1-26. University of Western Australia Press: Perth.

Blakely, W. F., McKie, E. N., and Steedman, H. S. (1938). Descriptions of four new species and two varieties of eucalypts. *Proceedings of the Linnean Society of New South Wales.* **63**, 65-69.

Brown, A. H. D. (1978). Isozymes, plant population genetic structure and genetic conservation. *Theoretical and Applied Genetics* **52,** 145-157.

Brown, A. H. D. (1979). Enzyme polymorphism in plant populations. *Theoretical Population Biology* **15,** 1-42.

Brown, A. H. D., Matheson, A. C., and Eldridge, K. G. (1975). Estimation of the mating system of *Eucalyptus obliqua* L'Hérit. by using allozyme polymorphisms. *Australian Journal of Botany* **23,** 931-949.

Burgess, I. P., and Bell. J. C. (1983). Comparative morphology and allozyme frequencies of *Eucalyptus grandis* Hill ex Maiden and *E. saligna* Sm. *Australian Forest Research* **13,** 133-149.

Chippendale, G. M. (1973). *Eucalypts of the Western Australian Goldfields (and the Adjacent Wheatbelt).* Australian Government Publishing Service: Canberra.

Chippendale, G. M. (1988). *Eucalyptus, Angophora (Myrtaceae), Flora of Australia. Vol. 19.* Australian Government Publishing Service: Canberra.

Clegg, M. T., and Brown, A. H. D. (1983). The founding of plant populations. In *Genetics and Conservation.* (Eds C. M. Schonewald-Cox, S. M. Chambers, B. MacBryde, and W. L. Thomas.) pp. 216-228. Benjamin/Cummings: London.

Department of Conservation and Land Management. (1987). Native seed collection and storage. *Department of Conservation and Land Management Information Sheet* **5-87.**

Department of Conservation and Land Management. (1988). Broadscale direct seeding of trees on farms. *Department of Conservation and Land Management Information Sheet* **2-88.**

Edmiston, R. J. (1987). Natural regeneration of bush areas in W. A. *Department of Conservation and Land Management Information Sheet* **1-87.**

Ehrlich, P. R., and Murphy, D. D. (1987). Monitoring populations on remnants of native vegetation. In *Nature Conservation: The Role of Remnants of Native Vegetation.* (Eds D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins.) pp. 201-210. Surrey Beatty and Sons: Chipping Norton N.S. W.

Ford, H. A., Paton, D. C., and Forde, N. (1979). Birds as pollinators of Australian plants. *New Zealand Journal of Botany* **17,** 509-519.

Fripp, Y. J. (1982). Allozyme variation and mating system in two populations of *Eucalyptus kitsoniana* (Luehm.) Maiden. *Australian Forest Research* **13,** 1-10.

Gardner, C. A. (1961). Trees of Western Australia. *Journal of Agriculture, Western Australia* **2**, 578-585.

Gill, A. M. (1981). Adaptive responses of Australian vascular plant species to fires. In *Fire and the Australian Biota.* (Eds A. M. Gill, R. H. Groves, and I. R. Noble.) pp. 243-271. Australian Academy of Science: Canberra.

Gottlieb, L. D. (1977). Electrophoretic evidence and plant systematics. *Annals of the Missouri Botanical Garden* **64**, 161-180.

Gottlieb, L. D. (1981). Electrophoretic evidence and plant populations. *Progress in Phytochemistry* **7**, 1-46.

Hamrick, J. L. (1983). The distribution of genetic variation within and among natural plant populations. In *Genetics and Conservation.* (Eds C. M. Schonewald-Cox, S. M. Chambers, B. MacBryde, and W. L. Thomas.) pp. 335-348. Benjamin/Cummings: London.

Hamrick, J. L., Linhart, Y. B., and Mitton, J. B. (1979). Relationships between life history characteristics and electrophoretically detectable genetic variation in plants. *Annual Review of Ecology and Systematics* **10**, 173-200.

Holland, P. G. (1969). Weight dynamics of *Eucalyptus* in the mallee vegetation of southeast Australia. *Ecology* **50**, 212-219.

Hopkins, A. J. M., Brown, J. M., and Goodsell, J. T. (1987). A monitoring system for use in the management of natural areas in Western Australia. In *Nature Conservation: The Role of Remnants of Native Vegetation.* (Eds D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins.) pp. 337-339. Surrey Beatty and Sons: Chipping Norton N.S. W.

Hopper, S. D., and Moran, G. F. (1981). Bird pollination and the mating system of *Eucalyptus stoatei*. *Australian Journal of Botany* **29**, 625-638.

Jain, S. K. (1975). Population structure and the effects of breeding system. In *Crop Genetic Resources for Today and Tomorrow.* (Eds O. H. Frankel, J. G. Hawkes.) pp. 15-36. Cambridge University Press: London.

Jain, S. K. (1976). The evolution of inbreeding in plants. *Annual Review of Ecology and Systematics* **7**, 469-495.

James, S. H. (1982). The relevance of genetic systems in *Isotoma petraea* to conservation practice. In *Species at Risk: Research in Australia.* (Eds R. H. Groves and W. D. L. Ride.) pp. 63-71. Australian Academy of Science: Canberra.

Karron, J. D. (1987). A comparison of levels of genetic polymorphism and self-incompatability in geographically restricted and widespread plant congeners. *Evolutionary Ecology* **1**, 47-58.

Kelly, A. E., Coates, D. J., Herford, I., Hopper, S. D., O,Donoghue, M, and Robson, L. Declared rare flora and other plants in need of special protection in the northern forests region. Unpublished report. Department of Conservation and Land Management: Como.

Larson, A., Wake, D. B., and Yanev, K. P. (1984). Measuring gene flow among populations having high levels of fragmentation. *Genetics* **106**, 293-308.

Ledig, F. T. (1986). Heterozygosity, heterosis, and fitness in outbreeding plants. In *Conservation Biology: The Science of Scarcity and Diversity*. (Ed M. E. Soulé.) pp. 77-104. Sinauer Associates: Massachusetts.

Loveless, M. D., and Hamrick, J. L. (1984). Ecological determinants of genetic structure in plant populations. *Annual Review of Ecology and Systematics* **15**, 65-95.

Lucas, G., and Synge, H. (Eds). (1978). *The IUCN Plant Red Data Book*. International Union for Conservation of Nature and Natural Resources: Morges, Switzerland.

Main, A. R. (1987). Management of remnants of native vegetation-a review of the problems and the development of an approach with reference to the wheatbelt of Western Australia. In *Nature Conservation: The Role of Remnants of Native Vegetation*. (Eds D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J. M. Hopkins.) pp. 1-14. Surrey Beatty and Sons: Chipping Norton N.S. W.

McCredie, T. A., Dixon, K. W., and Sivasithamparam, K. (1985). Variability in the resistance of *Banksia* L. f. species to *Phytophthora cinnamomi* Rands. *Australian Journal of Botany* **33**, 629-637.

McNee, S. (1986). 'Pollination biology of *Eucalyptus rhodantha*'. Grad. Dip. Nat. Res. Thesis. Curtin University: Perth.

McNee, S. (1989). 'The Pollination Biology of *Eucalyptus rhodantha*'. M. Appl. Sc.Thesis. Curtin University: Perth.

Moran, G. F., and Bell, J. C. (1983). *Eucalyptus*. In *Isozymes in Plant Genetics and Breeding*. (Eds S. D. Tanksley, and T. J. Orton.) pp. 423-441. Elsevier: Amsterdam.

Moran, G. F., and Brown, A. H. D. (1980). Temporal heterogeneity of outcrossing rates in alpine ash (*Eucalyptus delegatensis* R. T. Bak.). *Theoretical and Applied Genetics* **57**, 101-105.

Moran, G. F., and Hopper, S. D. (1987). Conservation of the genetic resources of rare and widespread eucalypts in remnant vegetation. In *Nature Conservation: The Role of Remnants of Native Vegetation*. (Eds D. A. Saunders, G. W.Arnold, A. A. Burbidge, and A. J. M. Hopkins.) pp. 151-162. Surrey Beatty and Sons: Chipping Norton N. S. W.

Nei, M. (1975). *Molecular Population Genetics and Evolution*. North-Holland: Amsterdam.

Nei, M. (1978). Estimation of average heterozygosity and genetic distance from a small number of individuals. *Genetics* **89**, 583-590.

Nei, M., Maruyama, T., and Chakraborty, R. (1975). The bottleneck effect and genetic variability in populations. *Evolution* **29**, 1-10.

Phillips, M. A., and Brown, A. H. D. (1977). Mating system and hybridity in *Eucalyptus pauciflora*. *Australian Journal of Biological Sciences* **30**, 337-344.

Pryor, L. D. (1981). *Australian Endangered Species: Eucalypts*. Australian Government Publishing Service: Canberra.

Pryor, L. D., and Johnson, L. A. S. (1971). *A Classification of the Eucalypts*. Australian National University Press: Canberra.

Rye, B. L. and Hopper, S. D. (1981). A guide to the gazetted rare flora of Western Australia. *Department of Fisheries and Wildlife of Western Australia Unpublished Report No 42.*

Sampson, J. F. (1988). 'The Population Genetic Structure of *Eucalyptus rhodantha* Blakely & Steedman and its allies *Eucalyptus crucis* Maiden and *Eucalyptus lane-poolei* Maiden'. PhD Thesis. The University of Western Australia: Perth.

Sampson, J. F., Hopper, S. D., and James, S. H. (1988). Genetic diversity and the conservation of *Eucalyptus crucis* Maiden. *Australian Journal of Botany* 36, 447-460.

Sampson, J. F., James, S. H., and Hopper, S. D. (1990). The mating system and genetic structure in a bird-pollinated mallee, *Eucalyptus rhodantha. Heredity* In press.

Slatkin, M. (1985). Rare alleles as indicators of gene flow. *Evolution* 39, 53-65.

Soulé, M. E., and Simberloff, D. (1986). What do genetics and ecology tell us about the design of nature reserves? *Biological Conservation* 35, 19-40.

Turnbull, J. W. (1980). 'Geographic Variation in *Eucalyptus cloeziana*'. PhD Thesis. Australian National University: Canberra.

Wellington, A. B., and Noble, I. R. (1985a). Post-fire recruitment and mortality in a population of the mallee *Eucalyptus incrassata* in semi-arid, south-eastern Australia. *Journal of Ecology* 73, 645-656.

Wellington, A. B., and Noble, I. R. (1985b). Seed dynamics and factors limiting recruitment of the mallee *Eucalyptus incrassata* in semi-arid, south-eastern Australia. *Journal of Ecology* 73, 657-666.

Yeh, F. C., Brune, A., Cheliak, W. M., and Chipman, D. C. (1983). Mating system of *Eucalyptus citriodora* in a seed production area. *Canadian Journal of Forest Research* 13, 1051-1055.

0762-0190-2M