Chapter Seven

Procuring Food and Water

7.1 Introduction

For a reintroduced population to establish and survive in the "wild", the individuals in it must be able to locate and use the resources available at the release site. Principal among the resource needs of an animal is its requirement for sufficient nutritious food for basic maintenance. For the long-term persistence and growth of a population, the ability of animals to secure sufficient nutrients for reproduction and development of young becomes important. Whilst food supplements can be offered to animals during the early stages of establishment, the eventual goal of a reintroduction should be for the animals to be nutritionally self-sufficient. An investigation of the diet selection by released, and *in situ* bred, mala provides information critical in assessing the progress of animals towards being nutritionally self-sufficient. With this information it is possible to identify the influences of season and time-since-release on the nutritional status of the animals, and use this to plan future releases.

Previous dietary studies of the mala have identified the diverse nature of its diet, and the significant seasonal variation that occurs in response to changes in the availability, and quality, of preferred food plants (Pearson 1989, Lundie-Jenkins *et al.* 1993). As both these studies were undertaken on the previously extant wild population of mala at the Sangster's Bore site, they provide a useful baseline for comparison with animals released during the reintroduction experiment reported in this thesis.

This chapter examines the procurement of food and water by a reintroduced population of hare-wallabies, in the context of the population's transition from a release population to a self-sustaining reintroduced population (as described in Section 2.4.5). In doing so, it focuses on the significance of food and water limitations on population establishment, the differences between captive-bred and *in situ* bred animals, and the implications of these for management and monitoring of reintroductions.

7.2 Methods

7.2.1 Dietary analyses

Collection of faeces

Fresh faecal pellets of *L. hirsutus* were collected between March 1991 and July 1993. During the initial stages of the program samples were collected in the vicinity of each release site from a number of discrete aggregations of pellets, each of which was judged to represent a separate defecation from a single animal. These aggregations were bulked for analysis. Fresh pellets were identified through reference to control groups of pellets, and were characterised by the presence of a shiny (but dry) mucous coating. Once capture techniques were developed, faecal pellet samples were collected from individual animals. These samples were analysed as discrete samples to allow investigation of the effects of age, sex and time-since-release on diet selection. All samples were air dried and stored at room temperature in sealed plastic bags before being sent to the University of New England, Armidale, for analysis.

Microscopic analysis of plant material in faeces

The microscopic analyses of faecal pellets described in this report were carried out by Ms C.M. MacGregor at the University of New England, Armidale.

(1) **Reference material**

Plant species found in the release area were collected and stored in FAA, as well as being conventionally pressed and dried. An effort was made to obtain specimens of all plant parts as previous work had indicated that *L. hirsutus* preferentially selected for seed and fruiting bodies (Pearson 1988, Lundie-Jenkins *et al.* 1993). Identifications were made in Alice Springs with the aid of botanists from the Conservation Commission. A reference collection of dried specimens was then compiled for use in the field. The remaining FAA-stored specimens were sent to Armidale, where reference slides were prepared for use in identifying plant fragments from the faecal samples. These reference slides of plant epidermis were prepared by Ms MacGregor using the techniques outlined in Berman and Jarman (1987). Reference slides were also prepared to enable identification of lucerne chaff within the diet, as this was the supplementary feed provided for animals in the release area.

(2) **Faecal material**

Faecal samples were prepared and analysed using a modification of the procedures described by Ms MacGregor in Jarman and Phillips (1989). Slides prepared from each faecal sample were randomly searched, and 50 fragments of plant epidermis were identified and recorded. Where possible these fragments were identified to genus or species, and the plant part recorded. Unknowns were identified as either monocotyledonous or dicotyledonous. Fragments varied greatly in area, and hence the relative size of all fragments was also recorded by the analyst, with reference to an established size unit standard. This standard size covered approximately 100 epidermal cells of the commoner grass species. Contribution by each species to the sample was expressed in terms of relative area of epidermis inspected microscopically. The proportional occurrence of each identified species in a diet sample was determined by dividing the value for the area of epidermis of that species in the sample, by the summed area of epidermis for all species identified in the sample. For some elements of the analysis and interpretation of these results, percentage figures for each species were separated into leaf/stem components and seed/fruit components.

General comparisons between the diets for captive-bred and *in situ* bred animals were undertaken using one-way Analysis of Variance (ANOVA). The relationships between dietary composition and factors, including captive-bred vs *in situ* bred, time-since-release and time-since-rainfall > 50mm, were initially examined using Analysis of Variation (ANOVA) and simple correlation. More detailed investigations were conducted using agglomerative hierarchical fusion routines in PATN (Belbin 1990, 1995). The ASO module was used initially to generate an association-matrix based on the Bray & Curtis (Czekanowski) measure. Cluster analysis was undertaken using the UPGMA (Unweighted pair-group method using arithmetic averages) combinatorial function of Lance and Williams. This option was selected because it gives equal weighting to all objects. The GDEF module was used to define the resultant group and DEND was used to generate a dendogram to graphically depict the relationships. The PATN classification derived for the dietary samples was subsequently imposed onto a set of confirmatory variables, including age, sex, time-since-release and cumulative rainfall residual, using the GSTATS module.

Vegetation cover and moisture content of food plants

Sampling procedures are described in general methods section in chapter 4.

7.2.2 Water and energy turnover

Animals need sufficient quantities of both energy and water to sustain their major life processes. Careful husbandry of captive maintained animals ensures that these most basic needs are adequately met. Since captive-bred animals were used during this reintroduction, it was considered important to ascertain the degree to which captive-bred animals could meet their requirements for both energy and water following release. Such investigation would provide a direct physiological measure of the released animals' ability to adapt to a free-living existence, which was presumably characterised by a lower quality diet and increased demands of thermoregulation and activity, compared with captivity. In order to investigate the water and energy turnover patterns of released mala, a series of trials were conducted using the isotope turnover techniques of Lifson and McClintock (1966).

Water turnover in captive maintained mala

Water turnover rates for captive maintained mala were determined for both a summer (January) and winter (August/September) study period during 1991, based on ^{3}HOH turnover. During each of the study periods 6 hare-wallabies (3M & 3F) were captured from the captive facilities using long handled nets. After capture, animals were weighed with an electronic balance and an initial blood sample was obtained from a lateral tail vein using a pre-dried heparinised syringe and winged infusion kit, in order to measure background levels of ^{3}HOH. Each animal was then injected in a hind limb with preweighed doses of 37 Mbq ^{3}HOH in 1 ml. The animals were retained in hessian sacks for 3 hrs to allow the isotopes to equilibrate with the body water pool. A further blood sample was then obtained. The condition and reproductive status of each animal was checked, and animals were released back into their pens. Recaptures were made about 7-10 days later, and animals were weighed, bled and released back into their pens.

Water and energy turnover of reintroduced captive-bred mala

Measures of the water and energy turnover for captive-bred mala reintroduced at the Sangster's Bore release site were obtained for both a summer (January) and winter (August/September) study period during 1991, using the doubly labelled water (DLW) technique (Lifson and McClintock, 1966).

Free-ranging reintroduced hare-wallabies were captured using modified Bromilow traps (Kinnear *et al.* 1988) as described in Chapter 4. After capture, animals were weighed with a spring balance, and an initial blood sample was obtained from a lateral tail vein using a pre-dried heparinised syringe and winged infusion kit in order to measure background levels of ^{18}O and ^{3}HOH. Each animal was then injected in a hind limb with preweighed doses of 37 Mbq ^{3}HOH in 1 ml and 0.9 ml of 98 atom% ^{18}O (YEDA-Stable Isotopes, Israel). The animals were retained in hessian sacks for 3 hrs to allow the isotopes to equilibrate with the body water pool. A further blood sample was then obtained. The condition and reproductive status of each animal was checked, and animals were released at their point of capture.

Recaptures were made at night about 4-5 days later (in some cases a third recapture was made after 10 days). The animal was weighed, bled, its collar checked, and then it was released at the capture site.

Laboratory analyses

Blood samples were centrifuged, and the cells and plasma were separated and then frozen (c. -5°C). Water was extracted from the cell fraction by vacuum sublimation in Thunburg tubes (Vaughan and Boling 1961). The ^{3}HOH content of this distilled water was determined at the University of New England by Dr Ian Wallis using liquid scintillation counting of duplicate samples to within 1% accuracy. Another fraction of the distilled water was analysed for ^{18}O concentration by means of gas isotope-ratio mass-spectrometry at the CSIRO Division of Wildlife and Ecology in Canberra. Body-water pools were estimated from the dilution of injected isotopic water, by comparison with standard dilutions. According to the equations of Lifson and McClintock (1966) and Nagy (1980), CO_2 production rates and water fluxes were derived from the declines in the levels of isotopes in the body-water during the release period. It is assumed that any changes in body-water pools were directly related to changes in body mass, and that any changes in body mass were linear (Lifson and McClintock 1966; Nagy 1980). The diets of the mala contain carbohydrate as the predominant metabolic substrate, and hence the respiratory quotient was presumed to be equivalent to 1.0. Metabolic rate was therefore estimated using the thermal equivalent of 21.8 kJ L^{-1} CO_2 (Nagy and Martin 1985).

Statistical comparisons were carried out by ANOVA. Probability values of < 0.05 were taken to indicate statistical significance.

7.3 Results

7.3.1 Environmental conditions

Rainfall

The pattern of rainfall recorded at the Rabbit Flat meteorological station during the course of the food and water study, from March 1991 to July 1993, displayed the enormous variability typical of Australia's arid zone (Figure 7.1). Monthly rainfall totals significantly above average for the study area were recorded in January 1991 (267.6mm), February 1991 (208.6mm), January 1993 (134.2) and February 1993 (407.8). Intervening periods were characterised by generally average or below average rainfall.

Vegetation

The temporal patterns of total plant ground cover measured at four sites, two within spinifex and two within caliche environments, were strongly similar to rainfall patterns, with peaks of cover coinciding with major rainfall totals in Jan-Feb 1991 and Jan-Feb 1993 (Fig 7.2). This relationship was strongest for the caliche sites which contain a greater proportion of annual species compared with the spinifex dominated sites. The pattern for the mean plant moisture content values, pooled for eight common plant species, shows a similar relationship with rainfall (Fig 7.1) as that shown by total plant ground cover.

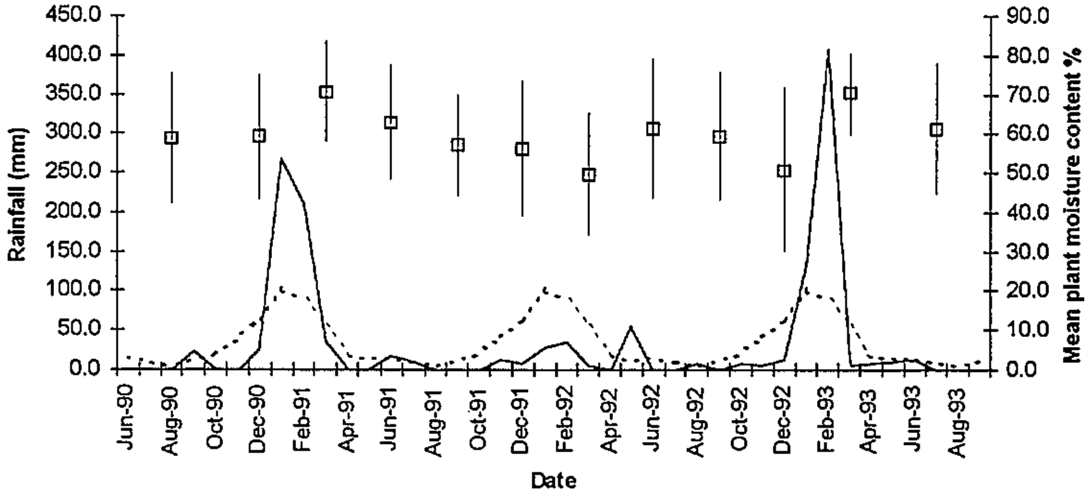


Figure 7.1 Relationship between changes in the mean moisture content for 8 common plant species and rainfall in the region between June 1990 and Sept. 1993. Long-term mean monthly rainfall (-----), Actual monthly rainfall (———), Mean moisture content of plant species (□).The following species were included in the plant moisture analysis; *Eragrostis falcata, Eriachne obtusa, Goodenia virgata, Hemichroa diandra, Melaleuca glomerata, Melaleuca lasiandra, Neobassia astrocarpa, Triodia pungens.*

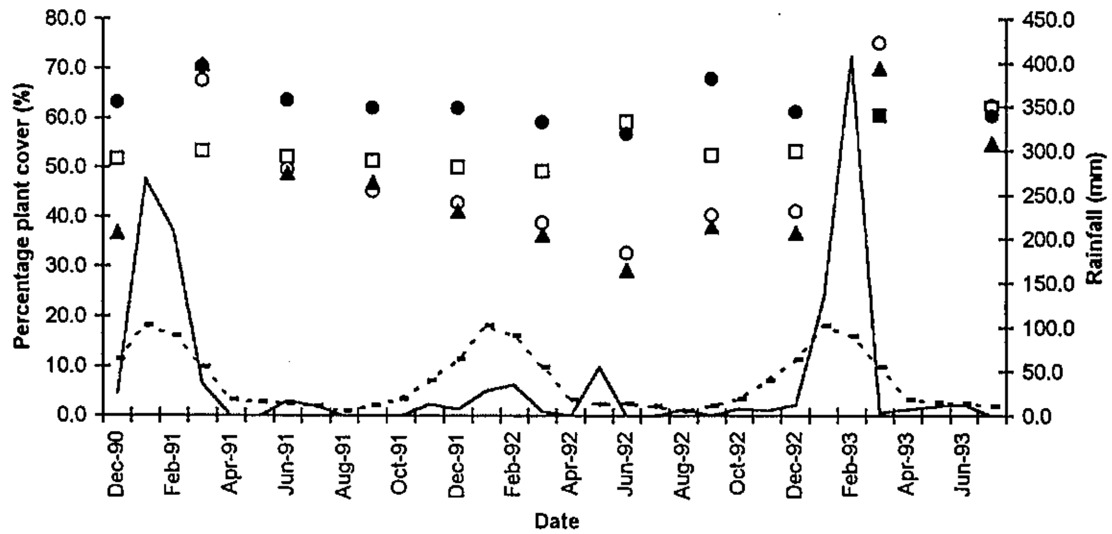


Figure 7.2 Relationship between the rainfall and percentage ground cover measured at four sites in the release area. Caliche sites - South = O, North = ●, Spinifex sites - South = ▲, North = □. Long-term mean monthly rainfall (------), Actual monthly rainfall (———).

7.3.2 Dietary study

Faecal Pellet Samples

A total of 78 separate faecal pellet samples were collected from 25 captive-bred (n=66) and 7 *in situ* bred (n=12) animals between March 1991 and July 1993. Because both survival and trappability differed between individual animals, the number of samples collected varied greatly between animals, ranging from 1 to 9 for captive-bred animals and 1 to 4 for *in situ* bred animals. In addition a further 9 samples were collected during the initial stages of the program, in the vicinity of each release site and from a number of discrete aggregations of pellets. As those scats could not be directly linked to an individual animal of known background they have not been included in some of the subsequent statistical analyses.

Plants detected in the diets of released and *in situ* bred animals

Table 7.1 lists the relative occurrence of different plant species that were commonly identified as components of the diet for both captive-bred and *in situ* bred animals, using microscopic analysis. A total of 38 species were distinguished on the basis of epidermal characteristics, with a further 9 classified as unknowns due to an inability to match epidermal characteristics with species within the reference collection. Of the 38 species identified, 37 were detected in the scats of released animals and 22 in the scats of *in situ* bred animals. Overall there were 16 species detected in the scats of released animals that were not detected in the scats of *in situ* bred animals, and only one species detected in the scats of *in situ* bred animals that did not occur in the scats of the captive-bred animals. In all cases, however, these species represented very minor components of the plant material recorded in scats. The larger number of species found in the scats of the captive-bred animals undoubtedly related to the number of samples analysed. A plot of the cumulative number of species detected in scats with increasing sample size predicts 29 species as a likely return from analysis of 12 scat samples, which is similar to the 22 species identified from 12 scats of *in situ* bred animals in this study (Fig 7.3). No adjustment was made to the data in relation to any possible effect of the seasonality of the samples from the two groups. As samples were obtained from both captive-bred and *in situ* bred animals over the range of conditions experienced during the study, it was considered that any effect of seasonal bias would be negligible.

Table 7.1
Relative contributions of items to the faecal samples from captive-bred and *in situ* bred mala
(Values are means from pooled data collected between March 1991 and July 1993)

Species		Captive-bred animals (n=66 scats)		*In situ* bred animals (n=12 scats)	
		mean % in faeces	No. of scats containing species	mean % in faeces	No. of scats containing species
Monocots					
	Aristida holathera	0.8	6	0	0
	Cyperus spp.	0.1	7	0	0
	Digitaria radulans	0.3	8	0	0
	Eragrostis eriopoda	0.8	8	0.8	1
	Eragrostis falcata	0.7	11	0.6	2
	Eragrostis sp.	16.5	44	17.7	11
	Eriachne aristida	0	0	0.1	1
	Eriachne obtusa	1.3	10	0	0
	Eulalia fulva	#	2	0	0
	Plectrachne sp.	#	2	0	0
	Triodia pungens	4.3	31	7.6	7
	Yakkira australiense	0.2	2	0	0
	Total monocots	**33.7**		**40.8**	
Dicots					
	Abutilon otocarpum	#	1	0	0
	Brunonia australis	#	4	#	1
	Cassytha filiformis	5.2	24	7.4	6
	Calandrinia remota	6.5	37	8.1	8
	Goodeenia virgata	0.6	10	0	0
	Goodeenia sp.	9.5	35	5.9	3
	Halosarcia halocnemoides	#	1	0	0
	Hemichroa diandra	0.6	15	#	1
	Neobassia astrocarpa	3.5	28	2.1	6
	Pluchea tetranthera	0.3	18	1.3	4
	Scleroleana cleandii	#	1	0	0
	Unknown b	5.9	56	4.8	10
	Unknown c	2.4	22	2.9	3
	Total dicots	**36.2**		**33.4**	
Groups					
	Leaf material	57.1		62.4	
	Seed material	23.9		22.7	
	Insects		6		2
	Supplements (lucerne chaff)	29.2	66	23.2	10
Mean No. of species per sample		8.1		8.7	
Mean species diversity per sample[@]		2.0		2.2	
Total number of species in all samples		37		22	

= Trace amount : mean amount in pooled diet <0.1%; [@]Shannon-Wiener Function

In general, the relative contribution of different plant species in the diets for captive-bred and *in situ* bred animals, as indicated by their mean occurrence in data pooled for samples from each group, were extremely similar with the only differences occurring for species that were relatively minor components of the diet.

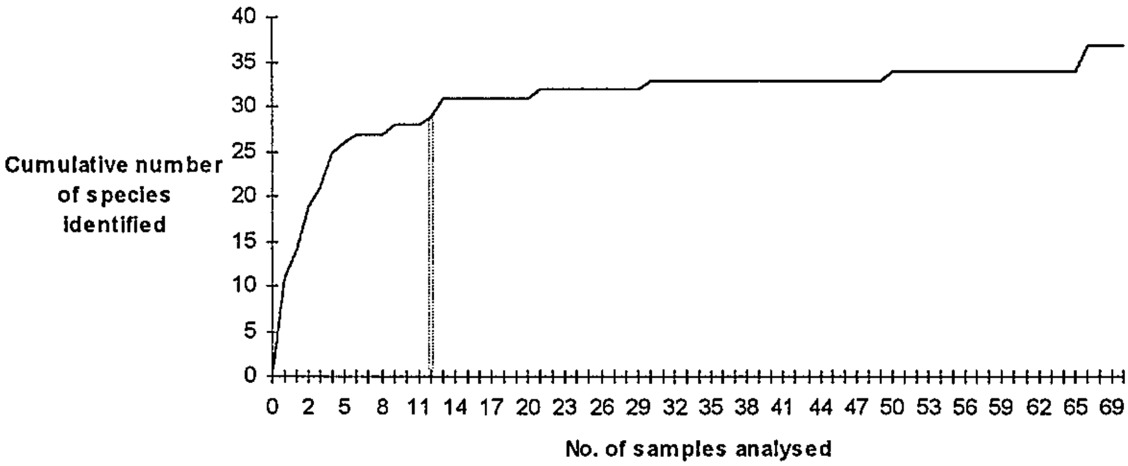


Figure 7.3 The relationship between number of faecal samples analysed and cumulative number of species detected for 66 samples from released hare-wallabies. Species composition data from 66 faecal pellet samples were randomly sorted and the incremental increase in the total number of species was calculated for the addition of each consecutive sample. (The vertical line indicates the cumulative number of species predicted for a sample of 12 scats)

The high level of supplement in the form of lucerne chaff detected in the diets of both groups is surprising as it might have been expected that *in situ* bred animals would depend less on such food sources. The proportions of lucerne detected in all faecal samples ranged to a massive 85%; and only 2 of the 78 samples (<3%) did not contain any lucerne chaff. The relationships between dependence on lucerne and factors including seasonal availability of other foods and time-since-release will be examined in detail in section 7.3.2

As identified in previous dietary studies of mala, seeds appear to be an important component of the diets for both captive-bred and *in situ* bred animals during the course of this project. Insects were recorded in several samples; however, the method of microscopic analyses used in this study does not permit their abundance to be quantified. The relatively low specific density of insect material means that it floats on top of the suspension prepared from faecal pellets, and is hence effectively eliminated from the pipetted samples used for preparation of microscopic slides. The value of insects in the diet of the mala has been examined previously by Lundie-Jenkins *et al.* (1993), and further investigation was not possible within this study.

The values for the mean number of species and Shannon-Weiner estimates of species diversity (Krebs 1978) were essentially identical for the samples from captive-bred and *in situ* bred animals. The values for both captive-bred and *in situ* bred animals suggest moderately diverse diets that include a range of the plant species represented at the release site.

Factors influencing the composition of the diet

Age and time-since-release

Faecal pellet samples obtained from individual captive-bred animals were allocated to categories of age and time-since-release. The results from the microscopic analyses for each sex were subjected to one-way analysis of variance to examine the influence of age and time-since-release on the use of lucerne supplements. No significant effect of either age ($F= 0.55$, 4 df, $P >0.5$) or time-since-release ($F= 2.23$, 6 df, $P>0.06$) upon use of lucerne was detected for female captive-bred animals. Whilst there was no significant effect of age ($F = 0.13$, 4df, $P>0.9$) on the use of lucerne by males, there was a significant effect of time-since-release ($F= 2.71$, 6 df, $P<0.04$). As the ANOVA's of the effect of time-since-release on the use of lucerne for both sexes were either significant, or tending towards significance, the relationship was further investigated by plotting the proportion of lucerne detected in individual samples for various classes of time-since-release (Fig 7.4). In order to eliminate any seasonal effect of lucerne intake, associated with the effect of rainfall of the relative availability of natural food sources, the classes of time-since-release were standardised by plotting them across the log value of total precipitation recorded in the two months prior to their collection date. In this way, if there was a predictable effect of time-since-release on the use of lucerne there should be a discernible separation of the samples across the plot area. No clear pattern or association was detected (Fig 7.4).

The degree of dependence by released animals on food supplements, and how this was influenced by time-since-release and environmental conditions, was further examined by construction of a correlation matrix to identify any relationships between parameters (Table

7.2).The table shows the Pearson product-moment coefficients describing the linear relationships between pairs of variables connected to the dietary analyses. A positive correlation implies that for an increase in the value of one of the variables, the other variable also increases in value. Conversely, a negative correlation indicates that an increase in value of one of the variables is accompanied by a decrease in value of other variables. The highlighted values in Table 7.2 indicate parameters in which greater than 50% of the variation can be associated to variation in another parameter. Several trivial correlations have not been highlighted as they are clearly not independent; these included those between age and time-since-release and between rainfall 1 month prior, and rainfall 2 months prior to collection of faeces.

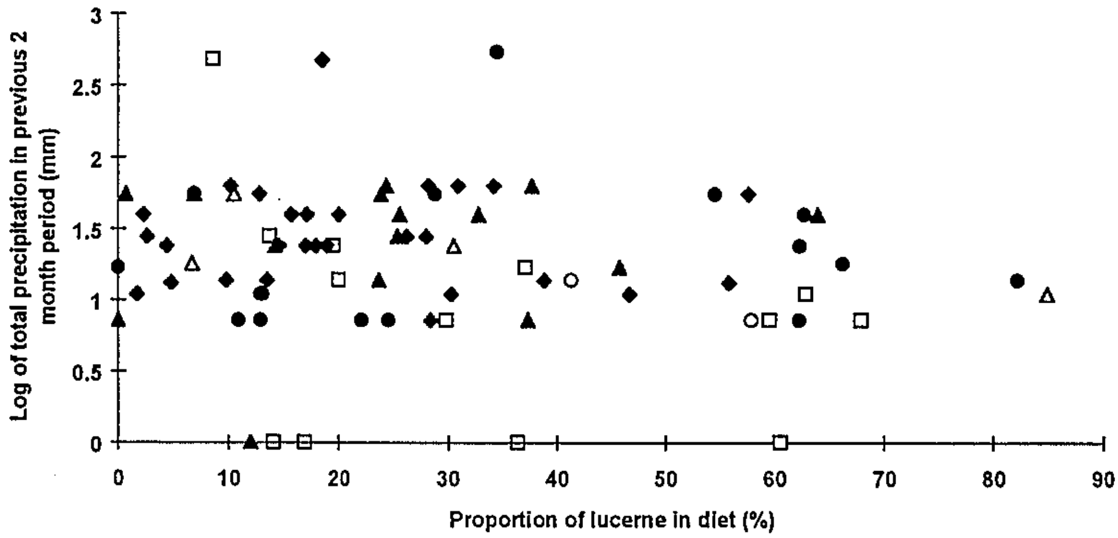


Figure 7.4 The relationship between the proportion of lucerne supplement detected in the diet and Log of total rainfall during the 2 months prior to the collection date for each sample. Different symbols indicate different classes of time-since-release (O = < 2 months, Δ = 2-4 months, □ = 4-6 months, ◆ = 6-12 months,● = 12-24 months, ▲ = >24 months).

The diversity of the diet as described by the Shannon-Wiener function was negatively correlated with the percentages of monocots and seed in the diet, and positively correlated with the percentage of leaf material. This suggests that diversity is higher when the diet is dominated by dicot leaf material. Correlations between the percentage of seed in the diet and both the percentage monocot (positive) and percentage leaf material (negative) reinforce the relationships between these parameters. The only other correlation coefficient greater than 0.50 is between the percentage seed

Table 7.2

Matrix of Pearson product-moment correlation coefficients defining the level of association between attributes of the animals' environment, and derived characteristics of the diet for captive-bred hare-wallabies released at the Sangster's Bore site.
(Highlighted values indicate parameters in which greater than 50% of their variation can be associated to variation in another parameter)

Parameters	Age	Time since release	Rainfall 1 month prior	Rainfall 2 months prior	Percent lucerne	Percent monocots	Percent seed	Percent leaf material	No. of species	Species Diversity[@]
Animal										
Age	1.0000									
Time since release	0.8581	1.0000								
Environment										
Rainfall 1 month prior	0.2438	0.2456	1.0000							
Rainfall 2 months prior	0.2041	0.2157	0.9442	1.0000						
Diet										
Percent lucerne	-0.0765	-0.1196	-0.1775	-0.2199	1.0000					
Percent monocots	0.1262	0.0114	0.1487	0.2431	-0.4202	1.0000				
Percent seed	-0.0014	-0.0190	0.1768	0.2847	0.5479	0.5463	1.0000			
Percent leaf material	0.0678	0.0947	-0.0950	-0.1872	-0.0105	-0.4091	-0.8080	1.0000		
No. of species	0.0334	0.2538	-0.0267	-0.0626	-0.1455	-0.4050	-0.2732	0.4743	1.0000	
Species diversity	0.0969	0.2387	0.0100	-0.1072	0.1441	-0.5178	-0.6350	0.6823	0.7623	1.0000

[@]Shannon-Wiener Function

and lucerne in the diet. The direction of this correlation is surprising as seeds are taken to be good quality food, and hence a heavy reliance on lucerne supplements would be unexpected during periods when the availability of good natural food resources was high. Previous studies have identified seeds as a seasonally favoured natural food source utilised extensively by mala (Pearson 1989, Lundie-Jenkins *et al.* 1993). One possible explanation for the anomaly inferred by the positive correlation between dietary seed and lucerne would be that seed is more available when the foliage of grasses is haying-off or gone. In this case, consumption of lucerne would be a substitute for the absence of palatable foliage. There were no strong correlations between any dietary parameters and measures of rainfall, time-since-release and age.

Associations between age, time-since-release, seasonal conditions and dietary composition for the released animals were further explored using Agglomerative Hierarchical Fusion routines in PATN. The dendrogram generated by this analysis (presented in Appendix 2) identified five groups based on a Bray and Curtis association matrix with a degree of separation of 1.02. The mean dietary characteristics of these groups are summarised in Figure 7.5 . This classification was subsequently imposed onto a set of confirmatory variables, including age, sex, time-since-release and cumulative rainfall residual, using the GSTATS. The results of this analysis showed a close relationship between the diet groups and recorded rainfall for 2 months prior to the sample, suggesting that rainfall may be influencing dietary composition in a predictable manner. There were no clear relationships with any of the other confirmatory variables tested.

The influence of rainfall on the dietary composition of these derived groups is most apparent for *Eragrostis*. The abundance and palatability of this perennial grass species would be strongly influenced by rainfall, and this would, in turn, affect its occurrence in the diet. The complete dominance of *Eragrostis* in GRP 1, in association with high rainfall, suggests that *Eragrostis* is strongly preferred when abundant and palatable. The pattern of occurrence for the ephemeral herb *Calandrinia* is less clearly related to rainfall, and this may reflect the relatively short period it is available to the animals. Flushes of *Calandrinia* typically emerge following periods of consistent rain, but dry off and die if insufficient follow-up rainfall occurs. In contrast, the perennial sub-shrub *Neobassia* persists in the environment under most conditions but is only utilised to a significant extent during the drier periods. It is probable that the use of *Neobassia* is affected by the availability of other preferred species. The relatively high water content of *Neobassia* may account for its elevated utilisation by animals during particularly dry times. The occurrence of the lucerne supplements in the diet is far from predictable and like *Neobassia* is probably moderated by the availability of preferred natural food plants. *Goodenia* is a small woody perennial herb which appears to fill the role of a secondary staple in the diet.

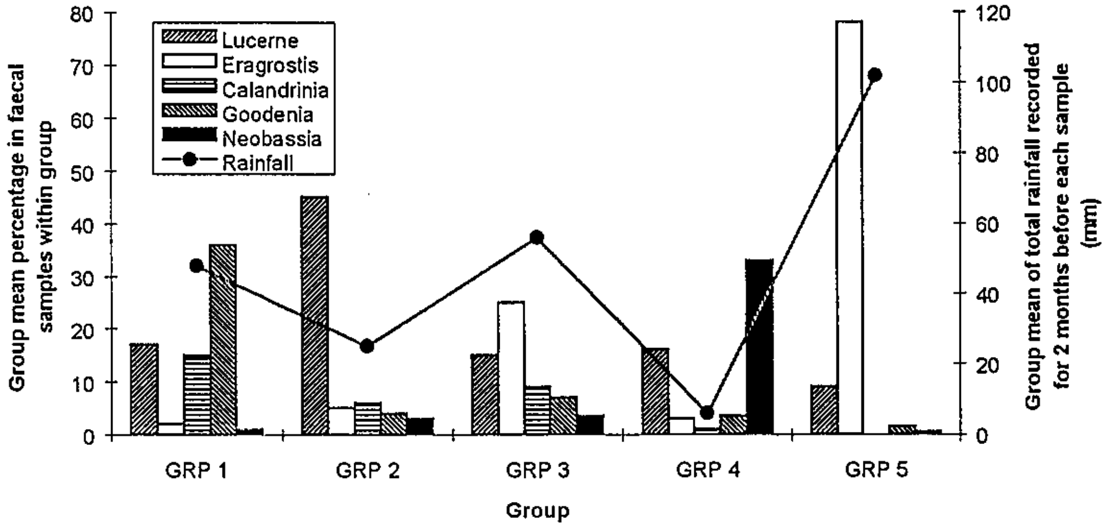


Figure 7.5 Graphical representation of mean species composition for 5 groups derived from Agglomerative Hierarchical Fusion in PATN. The relative relationship with rainfall is indicated by the overlain plot of group means for rainfall.

The relationship between rainfall and dietary composition, inferred from the PATN analysis, was further examined by a regression of the mean percentage of lucerne detected in the diets of free-ranging mala against cumulative residual rainfall (Fig. 7.5). This latter parameter is calculated in a similar fashion to the "residual mass" diagrams utilised by engineers, and represents the cumulated differences between long-term average monthly rainfall and actual monthly rainfall. It has been found to provide a useful means of illustrating ecologically meaningful trends in the surplus or deficiency of rainfall (Berman 1991). In the case of the present study it is apparent that the mean proportion of lucerne detected in the diet is significantly negatively-correlated to the cumulative residual rainfall ($r^2 = 0.44$, $P<0.05$). Hence the mean proportion of lucerne detected in the diets of free-ranging mala corresponded with periods when the cumulative residual rainfall was highly negative. Such negative values result from sequences of months during which actual monthly rainfall totals were considerably below long-term means. The two points which lie well below the regression line relate to extremely small sample sizes (2 & 3 scats respectively), and hence may be strongly influenced by the habits of the particular individuals represented in those samples. The graph also suggests that the dietary study was conducted during a relatively dry period, and extrapolation of the regression line towards the x axis suggests that during average or relatively wet periods, animals may utilise little of the supplementary food and instead may favour natural alternatives.

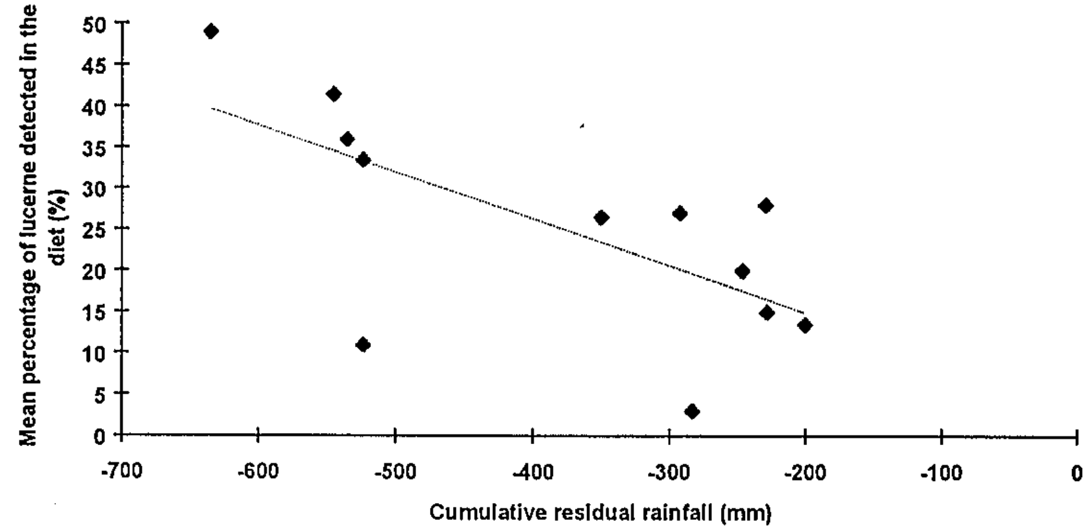


Figure7.6 Relationship between the mean percentage of lucerne detected in the diets of released mala and the cumulative residual of rainfall in the study area. ($r2=0.44$, $F=7.30$, $P<0.05$)

Environmental conditions

Figure 7.5 illustrates the substantial variation in the relative composition of the diet in relation to rainfall. Native grass species such as *Eragrostis* were detected in large amounts in the diet only when rainfall during the previous 2 months exceeded 50 mm. Conversely chenopod sub-shrubs such as *Neobassia* were most abundant in the diet during dry periods. Use of the food supplements appeared to fluctuate relative to different dominant native species. Given that the abundance of, and access to, lucerne at the release site are constant, it is apparent that during particular seasons the mala are selecting natural food plants in preference to lucerne. It is equally clear that the period of maximum abundance for lucerne in the diet (Group 2) has correspondingly low proportions of the major natural food items used during other periods. Whilst intuitively if one species contributes a high proportion to the diet the contributions of other species must be lower, it is interesting to note the evenness of the proportions for the other species in Group 2. The fact that all other species are uniformly low suggests that use of the lucerne supplement is driven by the relative availability of alternative natural food items. A plot of the changes in percentage ground cover (a reflection of availability of native plants), measured at sites within the study area, against the proportion of lucerne in the diet provides further evidence of such a relationship (Figure 7.2).

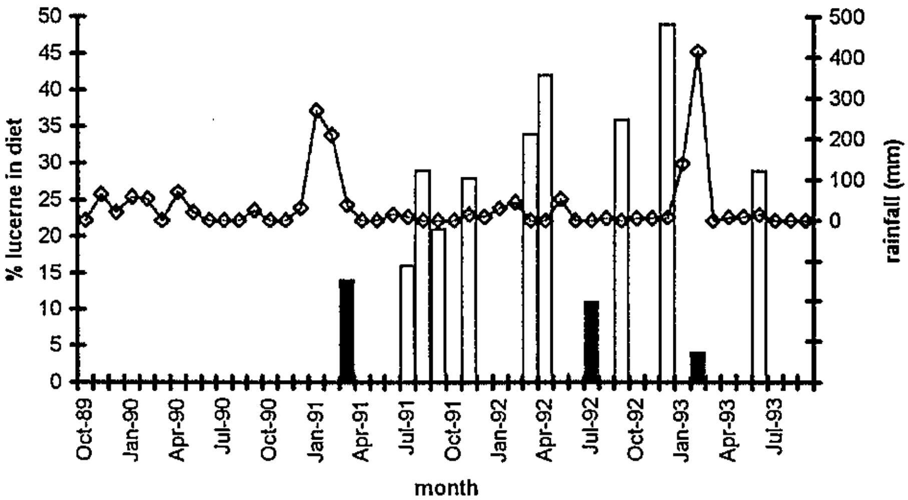


Figure 7.7 The changes in the proportion of lucerne in the diet (histogram) relative to pattern of actual rainfall (open diamonds) at the release site. The closed bars are the lowest proportions of lucerne in the diet and follow episodes of rainfall > 50mm.

The combined effect of extreme uncertainty of rainfall in the release site and diet selection, which is essentially rainfall-driven, means that the diet will also be extremely variable and liable to dynamic change, in relation to episodic rainfall events. Figure 7.7 clearly shows this effect whereby the proportion of lucerne in the diets is lowest immediately following episodes of rainfall, generally greater than 50mm. This proportion then increases steadily until another rainfall event triggers a response in the natural vegetation, as indicated previously in Figure 7.2.

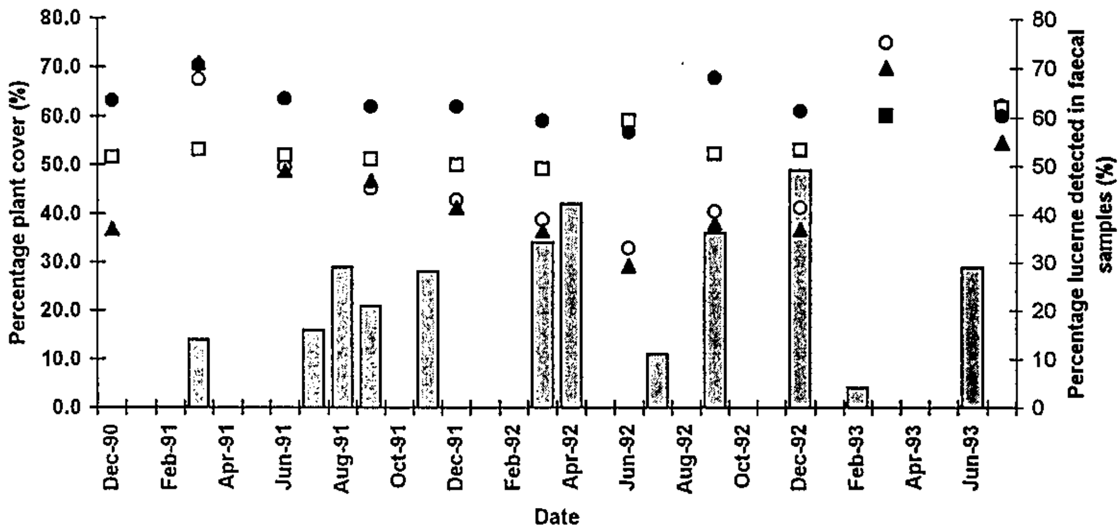


Figure 7.8 Relationship between the proportion of lucerne detected in the diet of released mala (shaded bars) and percentage ground cover measured at four sites in the release area. Caliche sites - South = O, North = ●, Spinifex sites - South = ▲, North = □.

Captive-bred vs *in situ* bred animals

Captive-bred and *in situ* bred animals showed similar patterns with respect to the types of natural food used, and the seasonal patterns of usage (Table 7.1) over the range of conditions encountered during the study. This suggests that *in situ* bred animals do not have an enhanced ability to select a diverse and seasonally appropriate diet compared with animals raised in captivity. As the population grows it is probable that animals will establish beyond the current network of supplementary feed points and these animals will need to be able to sustain themselves on natural foods.

7.3.3 Water and energy turnover

Field conditions

The summer field study period (January 1991) corresponded with a period of exceptionally high rainfall at the Tanami Desert site, and intermittent heavy rain fell throughout the period. The rainfall total for January was 267mm compared with a long-term average of 102 mm. In contrast, there was no rainfall recorded during the winter study period (August/September 1991). The average maximum air temperatures during 10 days in January and 8 days in September were 38°C and 35.3°C respectively; the corresponding minimum temperatures were 25.1°C and 12.3°C respectively. The conditions recorded in Alice Springs for the captive animals during both periods were similar, but less extreme.

Recaptures

During the summer field study period, seven animals (five females and two males) were injected with Doubly labelled water (DLW), five were recaptured twice and two were recaptured three times. Eight animals were injected in winter; three were recaptured twice and five were captured three times. Of the animals injected with DLW, four of the six females and one of the four males were studied in both winter and summer. During both sampling periods for the captive animals the same sample of six captive animals (3 males and 3 females) in the colony at Alice Springs were injected and recaptured three times each.

Body Mass

There were no significant differences in the body weights for either males or females between the study periods nor between the two sexes within each of the study periods, for both field and captive animals. Likewise within both study periods the body weights of individuals fluctuated little (<1%) and hence both field and captive animals were regarded as being in water and energy balance.

Comparative Total Body Water and Water-turnover rates in reintroduced and captive maintained animals

Total body water (TBW), estimated by tritium dilution, did not vary significantly between sexes or between sampled animals kept in captivity and those living in the field. There was, however, a tendency for females in the field trial to have a lower value for TBW in winter. There was not a similar trend observed for males in the field trial; however, this may be attributable to the relatively elevated TBW recorded for one male during the winter sample (TM083: TBW 86.8%). The low equilibration counts recorded for this individual suggest some problem with either leakage of isotope or equilibration time. If this value, which was

15% higher than the mean of the other values, is removed, the mean TBW for males shows a non-significant decrease from the summer period to the winter period of 80.1% to 75.7%. The change is based on measurements of only two animals in each sample period, and hence is non-significant and must be treated with caution. O^{18} background readings recorded for field animals were, however, significantly higher ($F= 52$, 1 df, $P < 0.0001$) during the winter sample period, and this difference is suggestive of some change in the vegetation status and/or the condition of the animals.

The water fluxes recorded for released and captive mala during the two sample periods are shown in Table 7.3. There were significant differences between the captive maintained and reintroduced animals during the summer (hot & wet) sample period, for both males and females (Table 7.3), when turnover rates were approximately 80% higher for the free-ranging reintroduced animals. In contrast, during the winter (cool & dry) sample period there was no significant difference in water turnover. There were no significant differences in water flux between males and females within each of the groups, despite many females carrying pouch-young of varying sizes.

Table 7.3
Water flux in captive-maintained and reintroduced mala
measured during summer and winter.
Values are means ± standard errors. Flux expressed as ml/kg.day.

	Male				Female			
	Summer	Winter	Results of AOV		Summer	Winter	Results of AOV	
			F Value	Prob.			F Value	Prob.
Captive	120 ± 1	94 ± 33	1.2	> 0.35	103 ± 11	96 ± 23	0.3	> 0.63
Reintroduced	180 ± 15	104 ± 24	15.3	< 0.03	186 ± 37	101 ±23	19.1	< 0.003
Results of AOV								
F Value	32.8	0.2			13.2	0.1		
Prob.	< 0.03	> 0.68			< 0.02	> 0.77		

Energy turnover in released animals

Data for body mass, TBW, CO^2 production and metabolic rates for each animal studied in the field during summer and winter periods are shown in Table 7.4. The means and probabilities of statistical difference calculated from one-way analysis of variance are shown in Table 7.5. There was no significant effect of either sex or season on body mass, Field Metabolic Rate (FMR) or the level of CO^2 production by reintroduced animals. There was, however, a significant reduction in the pooled mean value for TBW between summer and winter, principally due to a reduction in female TBW. Metabolic rate was strongly correlated with water turnover during the summer sample ($r^2 = 0.53$, $P < 0.07$), but not during the winter period ($r^2 = 0.05$, $P > 0.5$), reinforcing the shift in environmental conditions and/or diet between the two sample periods suggested by changes in TBW.

Table 7.5
The means and statistical significance of differences related to sex and season for body mass, total body water, field metabolic rate and CO^2 production measured in summer and winter at Sangster's Bore. (Significance of one-way AOV).

	Summer (wet)				Winter (Dry)				Seasonal Difference[@]	
	Male	Female	Results of AOV F Value	Prob.	Male	Female	Results of AOV F Value	Prob.	Results of AOV F Value	Prob.
Body Mass (kg)	139 ± 16	131 ± 10	0.79	> 0.4	138 ± 10	149 ± 13	1.51	> 0.2	4.12	> 0.06
Total Body Water (%)	80 ± 2	83 ± 4	1.09	> 0.3	79 ± 6	75 ± 3	2.00	> 0.2	7.81	< 0.02
Metabolism										
Metabolic rate (Kj kg^{-1} day^{-1})	357 ± 22	409 ± 124	0.30	> 0.6	472 ± 94	445 ± 64	0.24	> 0.6	1.77	> 0.2
CO_2 production (mL g^{-1} hr^{-1})	0.68 ± 0.04	0.76 ± 0.2	0.21	> 0.6	0.90 ± 0.2	0.84 ± 0.1	0.25	> 0.6	2.48	> 0.1

[@] Male and female data pooled within seasons for comparison

7.4 Discussion

It appears, from the results of the current study that both reintroduced captive-bred and *in situ* bred mala quickly learned to locate and forage on naturally occurring food plants. During the seasons sampled, both captive-bred and *in situ* bred mala maintained a diverse diet containing a range of species. Whilst animals from both cohorts showed an ongoing tendency to utilise the food supplements provided at the release site, both showed distinct preferences for particular natural food plants during periods when they were available. It was not possible to examine the level of dependence animals had on these supplements, as use of them varied significantly in relation to changes in the condition and availability of natural food sources. In this sense, the individuals within the reintroduced population were never forced (due to the prevailing environmental conditions and

Table 7.4

Details of body mass, body mass change, total body water (TBW), CO_2 production rates and field metabolic rates (FMR) for reintroduced mala at Sangster's Bore in summer and winter.
The number of data points for the measurement (an equilibrium time sample + recaptures) is shown in parentheses.

Animal	Summer (Wet)						Winter (Dry)				
	Mass (g)	Mass Change (%)	TBW (%)	FMR (kJ kg^{-1} day^{-1})	CO_2 prodtn (mL g^{-1} h^{-1})		Mass (g)	Mass Change (%)	TBW (%)	FMR (kJ kg^{-1} day^{-1})	CO_2 prodtn (mL g^{-1} h^{-1})
	Females										
176	1437	-0.06	89.9	436 (3)	0.833		1677	-0.57	72.1	552 (2)	1.056
178	1355	-0.02	79.7	566 (2)	1.082						
198	1325	+0.04	81.9	356 (2)	0.680		1395	-0.10	76.8	458 (2)	0.875
200	1370	-0.06	79.4	232 (2)	0.443		1530	-0.43	77.8	406 (3)	0.776
203	1187	+0.03	84.4	455 (3)	0.870		1340	+0.51	76.1	398 (2)	0.760
196							1530	+0.22	70.7	410 (3)	0.783
	Males										
83	1505	-0.01	78.8	341 (2)	0.652		1500	-0.39	86.8	381 (3)	0.728
93	1280	0.00	81.5	373 (2)	0.714						
308							1353	-0.50	74.5	467 (3)	0.892
676							1297	+0.50	76.9	569 (3)	1.087

provision of supplements) to explore fully the range of natural food plants that might be utilised by free-living "wild" mala during bad times.

Since previous dietary studies of free-living "wild" mala have been undertaken at the Sangster's Bore site, it is possible to examine the feeding strategies adopted by the captive-bred and *in situ* bred animals compared with free-living "wild" mala. Table 7.6 shows the relative contributions of different plant species in the diets for these 3 groups. Both the present and previous dietary studies included samples collected over both "wet" and "dry" years, and hence environmental conditions are considered not to have any influence. The most striking difference is the reduced proportion of monocot species utilised by both groups from the reintroduction program. The mean proportion of monocot material detected in the diet of "wild" mala was 71%, compared with values of approximately 34% and 41% for the captive-bred and *in situ* bred groups respectively. The relative ratios of monocot to dicot material in the three diets, excluding lucerne, also confirmed a reduced occurrence of monocots in both reintroduced groups. This reduced use of natural monocot species appears to be completely compensated for by their use of lucerne supplements. For the "wild" group, increased use of species including *Aristida holathera, Eriachne obtusa* and *Triodia pungens* contributed to their different pattern of use of monocots. All three species are perennial grasses that persist during drier conditions and act as important food sources during those times. The provision of food supplements clearly reduced the need for both groups of animals involved in the reintroduction to utilise these species in that manner. Consumption of dicots did not vary considerably across the three different groups.

The other notable differences between the dietary patterns of the animals within the reintroduced population, and those in the previous "wild" population, are the higher proportion of samples from the "wild" population containing insect material, and the greater values for both mean number of plant species per sample and mean plant species diversity for the "wild" population. In the case of insects, the previous dietary studies at Sangster's Bore (Lundie-Jenkins *et al.* 1993) found that the occurrence of insect material in the diet of mala peaked during drier periods when the relative availability of alternative foods was at its lowest. The provision of food supplements to the reintroduced mala would have reduced the necessity for animals to rely on insects as a food source, in much the same way as it has influenced their relative use of monocots.

Table 7.6
Relative occurrence of different dietary items recorded from the present study for captive-bred and *in situ* bred mala, compared with studies conducted previously on "wild" mala
(Values are means from pooled data collected over the entire length of each study)

Species		Reintroduced: Captive-bred animals (n =66) mean % in faeces	Reintroduced: *In situ* bred animals (n=12) mean % in faeces	"wild" population Lundie-Jenkins *et al.* 1993 (n=42) mean % in faeces
Monocots				
	Aristida holathera	0.8	0	7.4
	Cyperus spp.	0.1	0	1.9
	Digitaria radulans	0.3	0	0
	Eragrostis eriopoda	0.8	0.8	0
	Eragrostis falcata	0.7	0.6	26.8
	Eragrostis sp.	16.5	17.7	3.1
	Eriachne aristida	0	0.1	0
	Eriachne obtusa	1.3	0	8.3
	Eulalia fulva	#	0	0
	Plectrachne sp.	#	0	#
	Triodia pungens	4.3	7.6	14.1
	Yakkira australiense	0.2	0	#
	Total monocots	**33.7**	**40.8**	71.2
Dicots				
	Abutilon otocarpum	#	0	0
	Brunonia australis	#	#	0
	Cassytha filiformis	5.2	7.4	7.6
	Calandrinia remota	6.5	8.1	0.5
	Goodeenia virgata	0.6	0	4.6
	Goodeenia sp.	9.5	5.9	0
	Hemichroa diandra	0.6	#	0.6
	Neobassia astrocarpa	3.5	2.1	5.9
	Pluchea tetranthera	0.3	1.3	#
	Scleroleana cleandii	#	0	#
	Unknowns b	8.3	7.7	0
	Total dicots	**36.2**	**33.4**	28.8
Ratios				
	Monocots : Dicots	**1:1.07**	**1:0.82**	**1:0.40**
Groups				
	Leaf material	57.1 (70.5)$	62.4 (73.3)$	71.2
	Seed material	23.9 (29.5)$	22.7 (26.7)$	28.8
	Insects&	9	17	66
	Supplements (lucerne chaff)	29.2	23.2	NIL
Mean No. of species per sample		8.1	8.7	11.3
Mean species diversity per sample@		2.0	2.2	2.5
Total number of species in all samples		37	22	31

= Trace amount : mean amount in pooled diet <0.1%; & Proportion of samples containing insect remains;
$ Values in brackets corrected for proportion of lucerne in diet; @ Shannon-Wiener Function

The observed differences in the mean number of species per sample, and mean species diversity between animals within the reintroduced population and those in the previous "wild" population, could relate to either (i) differences in foraging behaviour/efficiency, or (ii) a further influence of supplementary feeding. Without detailed examination of the dietary preferences of individual animals in relation to the relative availability of different food plants, it is virtually impossible to explore the likelihood of differences in foraging behaviour/efficiency. Such an investigation would also be compromised by the provision of supplements to the reintroduced population.

The consistently high values for lucerne supplements in the diets of reintroduced animals, as reflected in the higher mean values >20%, acted both to increase the homogeneity of their diet and probably to reduce their need to locate and utilise as great a range of alternative food sources as the "wild" animals.

Whilst the present study did not incorporate any control to examine the merits of providing food supplements to reintroduced animals, a number of important points have been derived from the investigations conducted. Neither the captive-bred nor *in situ* born animals showed a total dependence on food supplements. In fact, as indicated in the introduction to this discussion, both groups displayed a preference to locate and utilise a diverse range of natural food. The lack of any apparent relationships between diet and the age of animals or time-since-release, at least over the period of this study, suggests that there is no extended familiarisation or learning process for the reintroduced animals. A more intensive study immediately following the release of animals would be required to ascertain if there was, in fact, any familiarisation or learning process. The apparent relationship between rainfall and the survival/recruitment of pouch-young into the reintroduced population (Chapter 5), suggests some potential relationship between the moisture or dietary status of the animals and pouch-young survival. The fact that this relationship exists, in spite of the continual presence of food supplements in the release area, may indicate that the long-term provision of food supplements is of little value in relation to population establishment and growth. Its primary importance may exist only during a brief period immediately following the release of captive-bred animals. The role of supplements would almost certainly change in relation to the patterning of productivity at different release sites. Knowledge of the relationship between pouch-young survival and rainfall-induced change in environmental conditions has implications in relation to timing release events, in order to maximise potential recruitment to the population.

The seasonal trends in water flux recorded in the reintroduced mala are similar to those shown by most other macropods (Green 1989). Such changes have generally been attributed to changes in the water content of herbage used by animals. Following wetter periods water may constitute 90% of fresh herbage, and animals consuming this herbage will consequently have a high obligatory water intake (Wallis *et al.* 1997). During the present study, the mean moisture content pooled for 8 species of plants known to be used by mala decreased by 13% between the summer and winter sample periods. When high levels of water are present in vegetation there would be no requirement for supplementary drinking water; however, previous studies have shown that as plant water contents decline to between 55% and 65%, herbivores must either access drinking water (Cooke 1982) or select more succulent dietary items (Ealey *et al.* 1965, MacFarlane 1968). The increased use of *Neobassia* by mala in drier months during the present study may illustrate adoption of the latter strategy. Under conditions where either of the above options for obtaining moisture are denied to herbivores, and hence they become deprived of water, food intake is likely to decrease and animals will lose weight (Cooke 1982). Ealey *et al.* (1965) recorded this phenomenon in Euros *Macropus robustus* which suffered a 25-40% weight loss when their natural diets declined to 30% moisture content. The implication of this in relation to the mala is that during extremely dry periods animals may be forced to limit their use of dry lucerne chaff supplements, in favour of alternative natural foods with higher moisture content but reduced nutritive value. In such circumstances animals could lose condition as a result of their poor quality diet, despite the availability of supplements, in order to maintain water balance. As an arid-adapted species, mala presumably have a number of physiological adaptations to cope with water restriction such as water resorption and concentration of urine. These were not directly investigated.

During the present study the only observed differences in water turnover between captive-maintained and reintroduced mala were skewed towards higher water intake by the reintroduced animals during the wet-summer period. This suggests that there was no significant adjustment required by the reintroduced animals with respect to maintaining water balance. Such a result should not, however, be interpreted as indicating that the provision of drinking water at the release site is unnecessary. The period over which the present study was conducted was extremely wet compared with long-term means for the area. As a consequence plant moisture could be expected to be elevated compared with average rainfall years, even during the seasonally drier winter sampling period. The fact that animals did have *ad libitum* access to water supplements is also likely to have elevated the water turnover rates for reintroduced animals, above those expected if water had not been available. Visual assessments of the frequency of use of water supplements based on tracks seen at watering points suggest, however, that animals made only limited use of these supplements. Understanding the relationship between rainfall and plant moisture would enable release events to be timed, to reduce any periods when water content of food was likely to be critically low. Timing release events in this manner would maximise the potential recruitment to the population.

The total body-water of an animal, its body mass and the body-water content (a percentage of body mass) are useful indices of its condition (Wallis *et al.* 1997). Changes in body mass due to growth, starvation or dehydration will change the size of the body-water pool, and the nature of these changes reflects the composition of the mass change. The reintroduced mala whose turnover rates were measured in summer (wet), and again in winter (dry), showed significant changes in percentage total body-water over this 5-6 month period. There was no appreciable change in body mass, and hence this change in TBW presumably relates to a change in the condition/body composition of the animals. Since free-ranging macropods maintain low levels of fat (Sinclair 1988), it is likely that the decreased TBW recorded for animals in the winter sample is a result of either a decrease in the quantity of water in the alimentary canal, or a decrease in the level of muscle mass (McDonald *et al.* 1982).

The field metabolic rates (FMR) determined for reintroduced mala were 2.1 and 2.5 times the values for standard metabolic rates for the summer and winter samples respectively, Standard Metabolic Rates (SMR) having been calculated using the equation of Dawson and Hulbert (1970). This ratio of the FMR:SMR, termed the "sustainable metabolic rate" (SusMR; Peterson *et al.* 1990), is a relative index of the increased energetic demands of free existence caused by activities including foraging, sheltering, thermoregulation, competition with other individuals and reproductive costs. The values recorded for mala lie at the midpoint of the range reported from other field metabolic studies of macropods (range 1.7 - 3.3; Green 1989). Hence on a plot of the field metabolic rate data for a range of macropod species on a log-log scale against body weight, the value for mala lies squarely on the regression line (Figure 7.8). In hindsight, it is apparent that a useful comparison could have been made between the field metabolic rates of captive-maintained animals and reintroduced animals, to more clearly identify the energetic costs of release. Unfortunately, the funds were not available for additional isotope labelled water to complete this more detailed study. The fact that released animals were able to survive and maintain body weight through the range of conditions experienced during this study is evidence that the energetic and nutritional demands of reintroduction are not beyond the animals' capabilities.

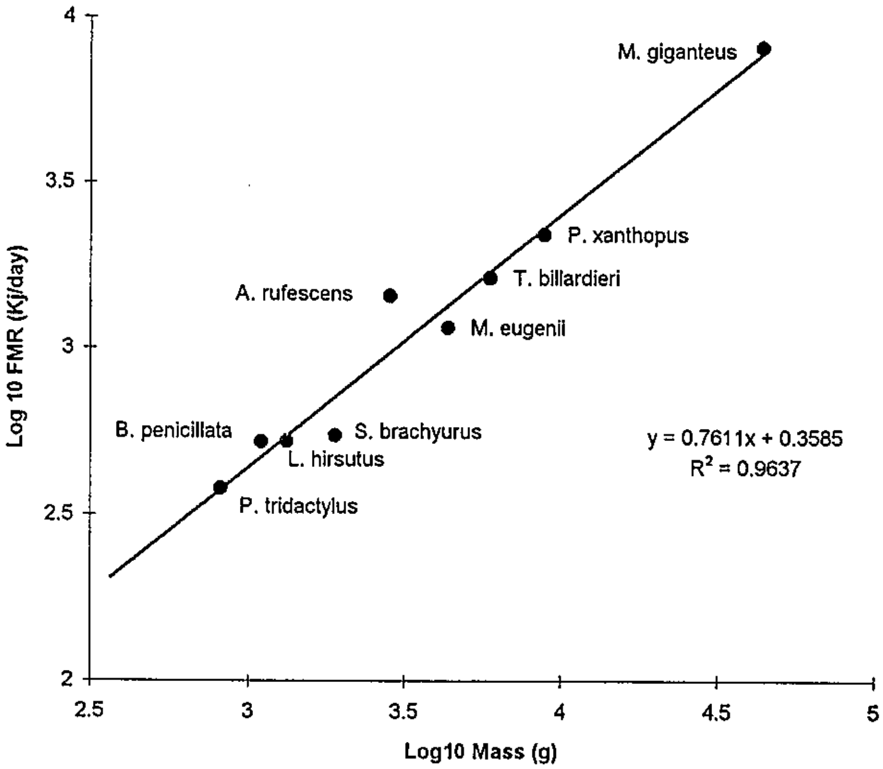


Figure 7.8 The relationship between body mass and field metabolic rate in macropods during summer (Modified from Green 1989 and Wallis *et al.* 1997).

Only three other studies of field metabolic rates in macropods have included both summer and winter measurements (Wallis & Green 1992, Wallis *et al.* 1997 and Green, Best and Turner, in press) (Table 7.6). During the present study, the winter field metabolic rate determined for mala was approximately 15% higher than the summer value. Whilst this difference was not statistically significant, all individuals that were measured in summer and winter sampling periods recorded higher FMRs in winter. This increase reflects the differences in both temperatures and food availability between the two sample periods. Lower winter night-time temperatures increase the energetic demands on individuals in relation to thermoregulation. The nocturnal activity patterns and nesting habits of mala are presumed to compensate for any potential thermoregulatory demand associated with high summer temperatures. The reduced availability of preferred natural food sources, during the drier winter period, may also have led to increased searching/foraging by animals to meet their energetic and nutritional requirements, leading to a corresponding increase in energetic demand.

Table 7.7
Comparative values of summer and winter field metabolic rates for small macropods from climatically different areas of Australia.

Species	Mean maximum temperatures (°C) Summer : Winter	Wet Season	Field metabolic rates (Kj/kg/day)			Source
			Summer	Winter	% change@	
Aepyprymnus rufescens	30.5 : 20.0	Winter	506	514	1.6%	Wallis & Green 1992
Bettongia penicillata	28.3 : 17.6#	Winter	476	632	32.8%	Green, Best & Turner, in press
Lagorchestes hirsutus	34.9 : 29.3	Summer	394	455	15.5%	This study
Potorous tridactylus	22.5 : 19.6	Winter	463	590	27.4%	Wallis *et al.* 1997

@ Percentage change from Summer FMR to Winter FMR ; # Temperatures from meteorological bureau data

Whilst the seasonal differences measured for mala were distinct, they were not as large as those recorded in similar studies of macropods from cool temperate climates (Table 7.7). Studies of *Bettongia penicillata* and *Potorous tridactylus*, which inhabit environments that typically have cool wet winters, reported differences between summer and winter FMR's of approximately 33% and 27% respectively. In contrast, the study by Wallis and Green (1992) of *Aepyprymnus rufescens* in north-eastern N.S.W. found only a 2% difference between summer and winter FMRs. Wallis and Green (1992) suggest that the lack of any distinct seasonal change in FMR was a result of the combined effect of: (i) the absence of winter rainfall during their study , (ii) thermoregulatory properties of the species' nests, (iii) possible changes in coat characteristics, activity patterns or posture, and (iv) the coefficient of variation within DLW measurements. The implications of these results in relation to reintroductions/translocations are that the energetic demands of free-existence are greater in winter, and will vary according to the climate regime of the release site. Movements of captive stock from a region characterised by summer-dominated rainfall and high temperatures, to areas with winter-dominated rainfall and lower temperatures, should be timed to avoid the most extreme conditions, as these are likely to impose significant energetic demands on the animals.

Chapter Eight

Reintroduction of the Mala
General Discussion

8.1 Introduction

The fact that there are no remaining known wild populations of mala guarantees that reintroduction will continue to be a central component in their recovery. Opportunities to protect and enhance the species' status by other conservation actions have been lost. In much the same way opportunities to increase our understanding of the species' ecology and the factors influencing its persistence have also been lost. Recognition of these realities not only strengthens the argument that reintroductions should be undertaken as experiments in adaptive management, it dictates that they must occur. For other less endangered taxa the argument will not be as compelling, and hence must be justified in light of the real benefits that can be derived from such an approach. The remaining sections of this thesis will attempt to:

- Examine the direct outcomes from such an approach in relation to future reintroduction and recovery of the mala, and
- Re-evaluate the structure proposed in Chapter 2 as a general framework for decision-making, planning and evaluation of reintroductions for other endangered species.

8.2 Future reintroduction and recovery of the mala

8.2.1 Direct outcomes of the current program

Whilst the ultimate aim of any reintroduction is to establish a new self-sustaining population of a rare species, this should not be the sole criterion for assessing the success or failure of such a program. As all reintroductions are experimental in nature, they should be assessed in terms of the improvement in our knowledge of the species, and of the process of reintroduction. When viewed in this context the program conducted at Sangster's Bore has added greatly to our knowledge of the mala, the logistics and practicalities of reintroduction to a remote area, and the impact of introduced predators on small populations. This section will examine the direct outcomes from the program and their implications for future reintroduction and recovery of the mala. For consistency these will be examined in terms of the individual elements of the model presented in Chapter 2 (Figure 8.1).

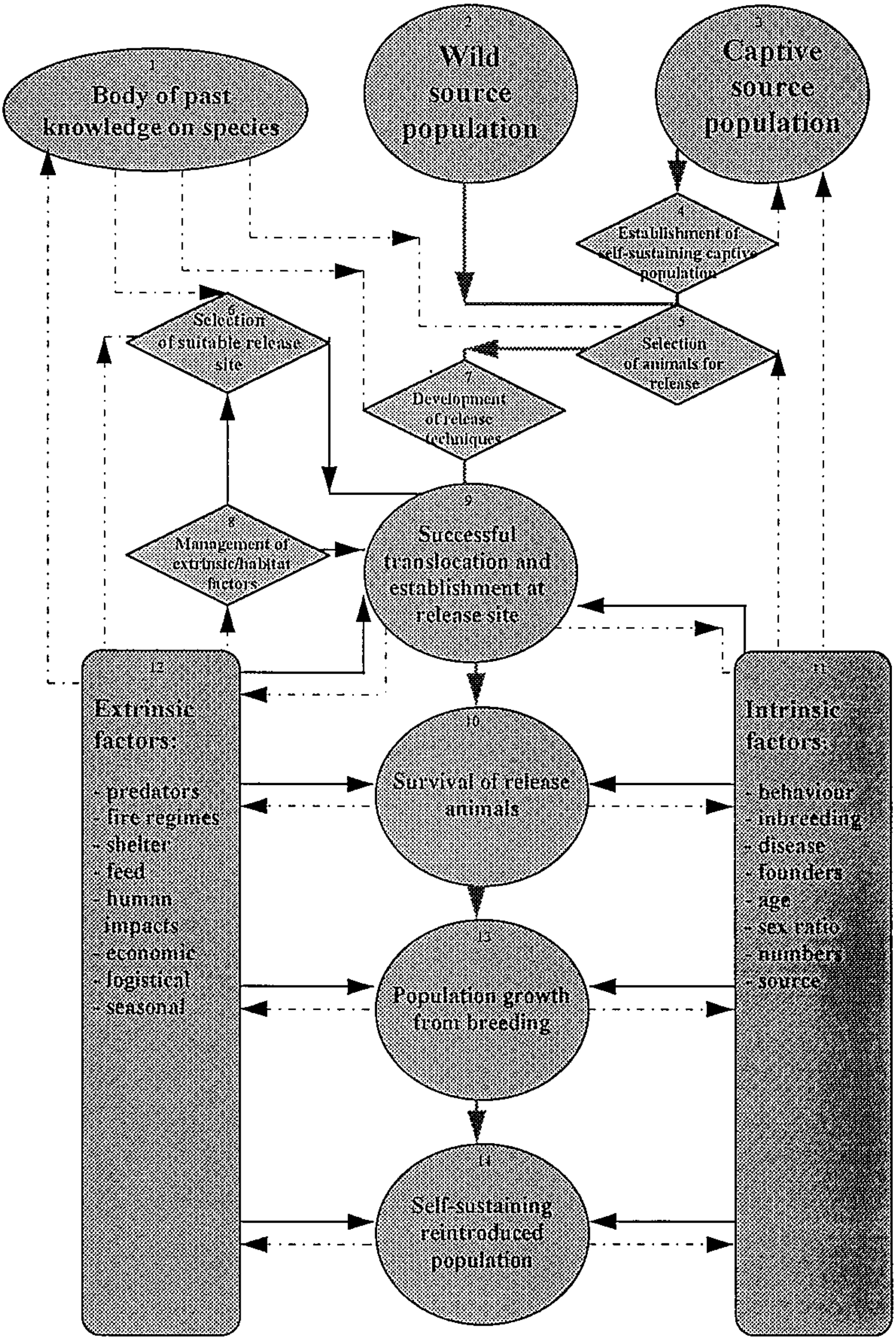


Figure 8.1 Theoretical framework for planning, decision-making and evaluation in an experimental reintroduction

Element 1: *Body of past knowledge on species*

As detailed in the preceding chapters of this thesis, the results of the present study have added considerably to the combined body of knowledge on the mala. It is also apparent that much of this information will have direct implications for future efforts to reintroduce the species. Whilst some of the knowledge derived from the present study may not have direct management implications in this program, it enhances the overall body of knowledge. Such information then provides the foundation for planning and decision-making in future programs.

Element 3: *Captive source population*

Within the time-frames of the current program and for the parameters investigated in this thesis, the available captive stock of mala appeared to be suitable for reintroduction. The absence of additional wild populations from which new founder stock can be obtained does mean, however, that genetic management of the captive populations will become both more important and more difficult with the passage of time. Whilst inbreeding levels are currently relatively low and there is no evidence of deleterious effects, it is inevitable that inbreeding levels will increase. Current management of the captive holdings of mala between three separated institutions will need to incorporate strategies for transfer of breeding stock, to ensure the genetic contributions of all breeding stock are equalised across the entire population. Use of the studbook management system SPARKS has been, and will remain, a key element in the genetic and breeding management of this population. This software includes functions that enable strategies to be routinely applied to population management, such as minimising inbreeding coefficients of pairings, and using mean kinship and founder representation to prioritise preferred matings within the population. As indicated in Chapter 3, adoption of such practices will maximise the retention of current levels of genetic diversity within the population.

The suitability of the available captive stock, in terms of both behavioural characteristics and disease susceptibility/carriage, remains untested in the ultimate sense. McLean *et al.* (1996; Appendix 3) suggested that a controlled experiment, comparing the survival of trained and untrained mala, would be required to ultimately test the value of pre-release training in predator recognition. Similar experimental designs would be required to evaluate incorporation of other behavioural modifications into future approaches to reintroduction. Although disease susceptibility and transmission by captive-bred stock have not been relevant to the current reintroduction program, they may become important if and when the stock, which were founded from Tanami Desert animals, are introduced to sites outside the Tanami Desert. The different conditions that may exist at other sites could increase the potential for disease-related problems.

Element 4 & 5: *Establishment of self-sustaining captive population*

There are two elements to the establishment of a self-sustaining captive population. Firstly, there is the numerical element: can the population produce a sufficient number of offspring for reintroduction and still maintain its own viability? The second element relates to the genetics of the population: can the population continue to provide stock that are genetically suitable for reintroduction? Clearly, for the mala, in relation to numerical self-sufficiency, the answer is a resounding "yes". The captive population has demonstrated its capacity to rebound following the removal of animals for reintroduction. The question of genetic sustainability has been addressed to some degree in the preceding discussion of captive founder stock. Continued monitoring of juvenile survival and reproductive output will enable managers to determine whether the population is suffering any measurable effect associated with the inevitable increase in inbreeding, resulting from a lack of new genetic stock to bolster captive holding.

Element 6: *Selection of a suitable release site*

The current biological criteria used in selecting sites for reintroduction/translocation of mala are based on a particularly limited data set on preferred habitat of the species. Without documentation associated with historical records for mala, our entire knowledge of the habitat preferences for the mainland mala is derived from studies of the Tanami Desert population (Bolton & Latz 1978, Lundie-Jenkins 1989, 1993). Hence the present study has confirmed, but not extended, those criteria. As a consequence, little additional information has been gathered that will influence the biological basis for selecting a release site.

The dietary studies conducted during this reintroduction program have essentially reinforced the findings of previous studies, and in doing so have provided further evidence to question the ability of the Sangster's Bore site to provide a constant source of quality forage for mala. Both the present and previous dietary studies (Lundie-Jenkins *et al.* 1993, Pearson 1989) suggest that mala may even be food-stressed, in what has been assumed to be their preferred habitat, during mild "drought" conditions. Lundie-Jenkins *et al.* (1993) concluded that, because of the inherently low and variable nature of primary productivity in the region, there was no steady succession of high quality, favoured food items to sustain mala through all seasons. As a consequence, during periods of below-average rainfall mala are forced to select plants with sustained productivity, such as saline-tolerant sub-shrubs and *Triodia pungens* which are fibrous and low in nutritive value. The poor survival of pouch-young to independence in the present study (except soon after relatively high rainfall (> 50mm)) implies a strong link between recruitment and the availability of quality forage. Close monitoring of diet selection and adaptation by mala released at sites with different vegetation dominance and dynamics will provide additional information to examine the question of "preferred habitat" from a dietary perspective.

One assumption associated with the selection of the Sangster's Bore site for this experimental reintroduction that the present study has disproved, is that predation of mala could be managed to an acceptable level. Despite ongoing efforts to control foxes and feral cats at the release site, episodes of predation had a significant impact on the reintroduced population. In light of these short-comings in current predator control measures, future site selection should, where possible, focus on areas carrying low or zero densities of predators.

The idea that non-biological factors are often as important as biological factors in the process of selecting a release site has been discussed previously in Chapters 2 and 4. Whilst most of the focus of the investigations in this study has been on the biological factors, it is appropriate that the non-biological elements relating to the program also be reviewed.

As stated in Chapter 4, the cooperation and assistance of Aboriginal people have been key components in this, and previous, attempts to reintroduce the mala. Whilst this statement remains true, recent conflicts between the Northern Territory Parks and Wildlife Commission and the Central Land Council have led to some uncertainty about future access to and management of the Sangster's Bore release site. Added to these recent events is the ongoing stalemate between these organisations over the negotiation of jointly managed conservation areas in the Tanami Desert. Without continued certainty of tenure or negotiated agreements about access and future management, the long-term future of reintroduced populations on Aboriginal lands remains uncertain.

A review of the other logistical aspects of the current program provides little new information likely to influence future reintroduction decisions. The remoteness of the Sangster's Bore site added considerably to the total cost, and hence influenced the intensity and frequency of monitoring and management undertaken. Without a direct comparison against an alternative site it is impossible to surmise if a less remote site which permitted higher intensity of monitoring and management would have ultimately faired any better in establishing a mala population. In general however, all other things being equal, sites that were less remote and favoured a higher intensity of monitoring and management would be preferred over more remote sites.

Element 7: *Development of release techniques*

The procedures for physically transferring captive mala from Alice Springs to the remote release site in the Tanami adopted during this study were particularly successful. These movements caused negligible mortalities, and those were directly attributable to breakdowns in adherence to the protocols. The incident in which animals were lost to heat stress was a direct result of those animals being held for an extended period in the vehicle without air-conditioning. Whilst it has been suggested that sedation of the animals should be routinely undertaken when animals are being transported for long distances, there is no evidence that such an approach would be beneficial for mala. The evidence from the substantial number of transfers of mala between Alice Springs and both other institutions and release sites does not suggest a need for the use of sedatives, provided animals are carefully handled. This includes minimising the stress of the capture event, minimising the length of the transfer event, avoiding exposure to heat and noise, and providing animals with moist feed whilst in transit to increase humidity (avoid drying out) and to enable some feeding.

Whilst there was no attempt to compare so called "hard release" and "soft release" techniques during the present study, there appear to be several advantages to the soft release technique and no observable disadvantages. As detailed in Chapter 4, the advantages of the soft release technique were that it:

- Enabled animals to be monitored both for any adverse effects or injuries associated with the actual transfer from the captive population to the remote release site, and for proper functioning of their individual telemetry collars.
- Ensured that transferred animals had immediate access to easily located food and water which were provided in the holding/release pens. Hence captive animals were not immediately required to locate and utilise natural food resources.
- Forced animals to locate and establish shelters within the enclosure which was considered likely to increase their fidelity to the release site and hence reduce the likelihood of animals dispersing large distances, possibly into inhospitable habitat, following free-release.
- Enabled the timing of the free-release to be varied to avoid major thunderstorms or windy nights that might have influenced the behaviour of animals upon release.
- Provided through the fences of the temporary holding/release pens a means for newly transferred animals to interact with animals already established at the site, without the potential for injury or forced dispersal that might have resulted from an initial direct confrontation.

It is conceivable that "hard release" techniques might be more appropriate for releases involving transfer and release of *in situ* or wild-bred animals over relatively short distances and time periods. The original planning for the current program had optimistically included the monitored relocation of *in situ* bred animals to other sites in the Sangster's Bore region, identified from extensive ground surveys carried out by the Conservation Commission during December 1987 (Lundie-Jenkins 1989). Unfortunately the poor recruitment and growth by the reintroduced population did not make a release of this type feasible.

Element 8: *Management of extrinsic/habitat factors*

The current program and previous research on mala has highlighted a number of extrinsic factors that require management. The most significant of these factors is predation by foxes and feral cats. Equally crucial is the lack of an effective means of controlling or mitigating the impact of these predators on a released population of mala. The combination of these two facts indicates that, until such time as effective means for controlling the impacts of introduced predators on establishing populations are developed, reintroductions would be most profitably pursued in environments with few or no predators.

Previous research has identified the significance of fire to the habitat requirements of mala within the spinifex-dominated habitats of the Tanami Desert (Bolton & Latz 1978, Lundie-Jenkins 1993). In these environments carefully managed programs of controlled burning are used to manipulate the components of the spinifex habitat that provide shelter and feed. Reducing the risk of wildfire in these homogenous environments is further reason supporting the deliberate management of fire regimes in spinifex-dominated habitats. The significance of fire to mala in other environments has, however, been questioned. Short & Turner (1992) suggest that the two sub-species of *L. hirsutus* on Bernier and Dorre Islands survive in environments in which fire is infrequent or absent. For habitats that differ in character from the Tanami Desert, some experimental monitoring of vegetation and animal responses to fire may be required, in order to develop appropriate fire management strategies.

The wildfire that destroyed most of the habitat supporting the last known wild population of mala in the Tanami Desert, in November 1991, is thought to have resulted from a fire deliberately lit by people travelling on the main access route that traverses the Tanami. A previous incident, in which large road construction equipment disturbed habitat occupied by mala in the vicinity of the access road (Lundie-Jenkins 1989), highlights the need to include human disturbance as an extrinsic factor likely to impact on the successful establishment of a reintroduced population. In the two examples presented here, formal communications were initiated with the Department of Transport and Works and the Central Land Council, to indicate the significance of the site and enact means of avoiding any potential future impacts. As a result of this process, signs were erected that identified the area as a fire protection zone and reinforced the restriction on vehicles travelling outside the defined road reserve.

Element 9: *Successful translocation and establishment at release site* and
Element 10: *Survival of release animals*

The initial release and short-term establishment of captive-bred mala at the release site was encouragingly successful at Sangster's Bore. The short survival time-lines recorded for a number of animals during the initial release are attributable to the failure of radio telemetry collars. Those initial releases aside, most animals translocated from Alice Springs survived for reasonable periods after release and showed an ability to locate and utilise natural food resources. This success suggests that the selection and release techniques employed during this program, and the environmental conditions that prevailed, favoured at least the short-term survival and establishment of captive-bred animals. Without any deliberate comparative trials to test alternative selection and release techniques, it is impossible to suggest any changes that might have enhanced survival and establishment.

Element 11 & 12: *Intrinsic and Extrinsic factors*

The majority of the factors that have acted on the reintroduced mala during the present study had been identified during previous research on the species. Whilst the present study has not added substantially to this list it has provided a means for both investigating their nature and quantifying their impacts on an establishing population. The details of these new insights have been discussed at length in previous sections.

Element 13: *Population growth from breeding*

Even at the low densities of animals encountered during the present study the population appeared to have no problem breeding successfully. Females with pouch young were recorded throughout the study across all seasonal conditions. However, even under the most favourable conditions of rainfall and predators experienced during the program, juvenile survival rates were low and natural recruitment to the breeding population was slow. Therefore the major problem is not one of breeding but of survival of young, and it stands out as the primary reason limiting the passage of the reintroduced population to a self-sustaining reintroduced population. The factors contributing to this situation have been identified previously and include episodes of extreme predation, dispersal by juvenile males and the effect of low rainfall on diet selection and nutrition.

Element 14: *Self-sustaining reintroduced population*

Obviously this stage was never reached in the present study; however, it is worthwhile at this point to consider the criteria that might be applied to measure achievement of this stage. Whilst it may be possible to suggest a general set of criteria, some will vary according to the species and habitats involved. Numerical measures such as the size of a population and its persistence time will vary with both intrinsic (reproductive rates, longevity and dispersal) and extrinsic (environmental productivity and variability) factors. Application of a simple generic population size criterion (> 500 individuals), such as applied by Beck *et al.* (1994), does not recognise the significance of such variations to assessing whether a population is self-sustaining.

Changes in a population's rate of increase provide an indication of a population's ability to sustain itself under different environmental conditions. For this reason rate of increase has been suggested as a possible indicator of the long-term sustainability of a population (Dexter pers. comm.). The rate of increase of a population is a combined function of the fecundity rate, the mortality rate and the age distribution of the individuals within the population. Under favourable environmental conditions a population increases (has a positive rate of increase) as fecundity increases and mortality declines (Caughley and Sinclair 1994). Conversely, under poor conditions a population may decline (have a negative rate of increase). Under normal circumstances the rate of increase of a population of vertebrates usually fluctuates gently for most of the time around a mean of zero (Caughley and Sinclair 1994). For a reintroduced population in the initial stages following release, provided conditions at a selected release site are favourable, the rate of increase should approach its maximum or intrinsic rate of increase. As the population grows, competition for resources within the population will inevitably increase, and there will be a related decline in rate of increase. A population which displayed a long-term mean rate of growth which was zero or positive across a range of environmental conditions would generally be considered self-sustaining. By contrast, a population which displayed a long-term mean rate of growth which was negative is likely to decline to extinction.

The persistence time of a population is particularly important in an uncertain environment such as the arid zone, where rainfall and hence primary productivity are extremely variable. For a population to be self-sustaining over the long term it must be able to persist through the full range of conditions likely to be encountered, excluding catastrophic and unpredictable events. In more mesic and predictable environments the viability of a population could reasonably be assessed over a shorter time frame. Long-term climatic records could be used to estimate appropriate time frames, over which a population would have a high probability of experiencing a full range of environmental conditions. Persistence of a reintroduced population over such a time-frame would suggest that the population was capable of sustaining itself in the long-term, in the absence of catastrophic and unpredictable events.

Population Viability Analysis (PVA) has also been suggested as a possible means of assessing the long-term prospects of a reintroduced population (McCallum 1995). The PVA process uses a combination of analytic and simulation techniques, to estimate the probability of a population persisting a specified time period into the future (Possingham 1996). In most cases, however, the estimates of extinction probability are extremely crude as they cannot incorporate all factors, and don't adequately incorporate feedback among demographic or genetic components (Lacy and Clarke 1990). For this reason the value of PVA is not its ability to estimate extinction probability, but rather its ability to identify the relative importance of the factors that put a population at risk, and to assess the value of various possible management options. In adopting such an approach PVA is used to compare management scenarios in terms of their impact on a population's probability of extinction/persistence. Such technology has a role in planning and management associated with reintroductions, and is consistent with the systematic approach extolled in this thesis.

8.2.2 Review of the recovery plan

The results of the experimental reintroduction program detailed in this thesis have had a significant impact on the future direction of recovery efforts for the mala. Probably most significant amongst these is the finding that even with sustained predator control, episodic predation on reintroduced mala can render the populations non-viable. This, combined with the numerous technical and ecological insights obtained during this program, provides a strong basis for reviewing the direction of, and priorities within, the existing mala recovery plan. The following sections will examine the review process, in relation to both performance against existing actions and the effect of changes in our knowledge base on the identification of future actions.

The review process

Since the commencement of active conservation measures for the mala in 1978, the program has undergone considerable change and internal review. The more formal process of reviewing the content and implementation of the Mala Recovery Program commenced with the formation of the recovery team in 1993. The broad representation on the recovery team, including agencies from other former range states and non-government organisations, provided the impetus for this review and development of a more national approach to recovery of the mala. This initial internal review by the recovery team consisted of the following discrete steps:

- matching actual recovery efforts against specific actions within the written plan, and hence identifying progress towards implementation of the plan.
- identification of changes in the species' status or information base which might require refinement of existing actions or the definition of new actions.
- identification of the relative roles of organisations represented on the recovery team, in relation to each of the defined actions.
- revision of recovery plan objectives, criteria and costings.

The points below summarise the outcomes of this review process, in relation to implementation of the actions prescribed in the original mala recovery plan.

Research Phase

Action 1.1 **Assess the ecological processes by which translocated mala establish new self-sustaining populations.**

1.1.1 Habitat and site fidelity of age/sex/reproductive classes upon release,

1.1.2 Dispersal and Establishment of F2 and later generations, &

1.1.3 Mortality and recruitment patterns

As reported in Chapter Four, the reintroduction effort described in this thesis represents the third such program that has been implemented for the mala. The first two were undertaken in a freshwater paleodrainage line (Lander River) that traditional Aboriginal owners selected on the basis of habitat suitability and use by mala in living memory (reported in Lundie-Jenkins & Bellchambers 1995), whilst the most recent program (documented in this thesis) was conducted at the site of the colony that went extinct in 1987. Whilst the two earlier trials were essentially conducted in a management framework, the results from each have had a substantial impact on our thinking in relation to future recovery plans and management of the mala.

Action 1.2 ***Determine cost effective methods for stress mitigation, to optimise establishment of reintroduced mala.***

1.2.1 Delivery and use of artificial food and water supplements

Information pertaining to this action including dietary analyses and isotope turnover studies has been examined and reported in this thesis (Chapter 7).

Action 1.3 ***Determine habitat management requirements in the post establishment phase.***

1.3.1 Movement patterns, survival and dispersal in response to fire

This action has not been implemented, subject to a more thorough revision of the recovery plan. It is recognised as an important management question but no action is recommended until reintroduced populations are established, and the populations of the two island sub-species of *L. hirsutus* are resurveyed.

Action 1.4 ***Clarify the status of the 3 recognised subspecies and establish genetic relationships among individuals in the captive breeding colony.***

1.4.1 Clarification of subspecific status through DNA analysis of the two island sub-species of L. hirsutus and the mala, &

1.4.2 DNA fingerprinting of captive and released populations

As described in Chapter 3, aspects of the genetic component of the recovery plan have been undertaken cooperatively between the Conservation Commission of the Northern Territory and Curtin University. Completion of this action was delayed by the problems in extracting sufficient quality DNA from Dorre Islands animals. Preliminary results indicate significant differences between both of the two island forms of *L. hirsutus* and mala. As reported in Chapter 3, these analyses also suggest an encouraging level of heterozygosity within the captive population. Additional analyses are also being undertaken by Dr Peter Spencer, under the auspices of the Cooperative Research Centre for Conservation and Management of Marsupials.

Management Phase

Action 1.1 ***Maintenance of naturally occurring mainland and island populations and those reintroduced to Sangster's Bore and the Lander River.***

1.1.1 Monitoring of island populations

Trips to Bernier and Dorre Islands by WA CALM and CSIRO Division of Wildlife and Ecology personnel have been undertaken for other research and management work, but no detailed survey work has occurred since that of Short and Turner (1992). Correspondence received from Dr Tony Friend of CALM (pers. comm.) suggests a possible decrease in the population of the Dorre Island sub-species of *L. hirsutus,* and highlights the need for a systematic resurvey of the populations for both island sub-species of *L. hirsutus.*

1.1.2 Management and monitoring of mainland populations.

Monitoring has been a key activity in relation to each of the mainland reintroductions undertaken to date. Controlled burning operations at both the Lander River and Sangster's Bore sites were increased, in response to large wildfires that had burnt in the vicinity of both sites during the 1994/1995 summer seasons. NOAA Satellite imagery has been used to assist in these operations, and the value of this approach has ensured that it will be incorporated in all future fire management.

Action 1.2 Maintenance of the captive breeding colony in Alice Springs

As reported in Chapter 3, the captive breeding program is currently divided between 3 institutions following the establishment of a small population at the Monarto Zoological Park in October 1994. All breeding and management of that population is being coordinated from Alice Springs using the SPARKS database, with assistance from Western Plains Zoo. There are no plans to greatly expand the current captive holdings of mala.

Preliminary trials into artificial breeding of mala were conducted at Western Plains Zoo, involving Queensland University. Semen was collected from 2 males transferred from Alice Springs, that had not successfully sired offspring. Future work will investigate storage and reclamation of semen samples, and oestrus detection in females. The work is not considered crucial to the recovery program for the species, as the current captive population is both self-sustaining and genetically diverse.

Action 1.3 Negotiation of conservation areas in the Tanami Desert with Aboriginal traditional owners.

Negotiations between the Conservation Commission of the Northern Territory and the Central Land Council have continued for establishment of conservation reserves in the Tanami, as required by the findings of the successful 1978 land claim. Minimal progress towards this end has been achieved, and no timetables have been set in relation to this process. As reported in section 8.2.1 there appears to be a frustrating impasse in negotiations between senior staff of both organisations.

Action 1.4 Reintroduction of mala to 2 major central Australian national parks.

1.4.1 Negotiation with Aboriginal traditional owners and relevant park agency on agreed procedures for executing a reintroduction program.

1.4.2 Preparation of a management prescription for cost-effective reintroduction and subsequent management.

1.4.3 Implementation of prescription at 2 areas coincidently to maximise efficiency of resources.

These actions have been excluded from the revised recovery plan in favour of other translocation options. Alternative sites both on offshore islands and in other regions of the mainland are considered to offer enhanced chances of successful establishment of mala.

The Revised Plan

The revised version of the "Recovery Plan for the Mala" was completed in 1995 (Lundie-Jenkins 1995) after significant consultation with the Mala Recovery Team and representatives of the member state agencies. This revised plan better reflected the national priorities for the mala, and incorporated results derived from implementation of the original plan. In addition, the plan was modified to account for the change in the species following the extinction of the only known "naturally occurring" mainland population of mala. The revised recovery plan has identified a number of potential new approaches to securing the species' future. A copy of the revised plan is attached as Appendix 3. The most significant amendments proposed in the revised recovery plan are listed below:

1. Translocation of the of mala to a predator-free, off-shore island.
2. Improved monitoring of the populations for both the Bernier and Dorre Island sub-species of *L. hirsutus*, and
3. Translocation of mala to secure mainland sites, including several sites in southwestern Western Australia as part of WA CALM's Western Shield Project, where extensive programs of fox and feral cat control are being conducted (Keith Morris, pers. comm.).

8.2.3 Future translocation and reintroduction options for the mala

The limited success of existing reintroduction programs demands that alternative approaches be examined in the interest of the long-term conservation of the mala. Potential sites for translocation of the mala exist both on the mainland and on offshore islands. In presenting these options the author has not presumed to evaluate the relative merits of each approach but simply provide several alternatives. As described in Chapter 2, a decision on these options will involve the consideration not only of biological imperatives but political, social and economic issues as well.

<u>Offshore Islands</u>

There are some 140 islands around the Australian continent that support, or have supported, at least 67 different marsupial species (Abbott and Burbidge 1995). Whilst some of these islands have been affected by some of the threatening processes associated with declines and extinctions on the mainland, the majority are largely unaffected. As a consequence these islands have acted as important refugia for threatened species and many have, in fact, been declared as conservation reserves. The relatively undisturbed nature of many of these sites, and the absence of exotic predators and competitors, makes these areas particularly attractive sites for translocation of species that continue to be threatened on the mainland.

Translocation to islands could provide important security for species, like the mala, that are facing extinction on the Australian mainland. However, there are relatively few islands suitable for species translocations, and often the establishment of a species on an island will close options for future translocation (ESAC 1995). This latter case would arise for species that have similar niche requirements. Thus proposals to translocate species to islands must consider:

- The suitability of habitat on the island.
- The potential impact of the introduction/reintroduction of a species to the island environment, and
- Other threatened species that might compete with the species under consideration.

Island environments can be particularly vulnerable to introductions of species. The introduction of the Tammar Wallaby *Macropus eugenii* to Granite Island in South Australia had a major detrimental impact on the island's vegetation (Copley pers. comm.). For this reason, the possible impacts of any translocation/introduction need to be thoroughly assessed.

To investigate the potential of island sites for translocation of mala, data-base records maintained by Dr Andrew Burbidge of the Western Australian Department of Conservation and Land Management (Abbott and Burbidge 1995, Burbidge pers. comm.) were examined. These records provided summaries of the size, habitat characteristics, exotic species, important native species and management and tenure associated with a large number of offshore islands. Whilst sites within the former known extent of the distribution for *L. hirsutus* would be preferred, it was decided that islands outside the distribution should not be excluded from initial consideration, as balancing the pros and cons of all options might highlight the need for such an approach. The critically endangered status of the mala provides ample justification for investigating all options.

The actual process of identifying and selecting island sites with potential for translocation of mala, as with the process of selecting any reintroduction/translocation site, involves consideration of a range of biological and non-biological factors (social, political, economic, logistic). Primary amongst these factors is establishing the size of island suitable to support a viable population of mala. Whilst this is essentially a biological consideration it will also be influenced by the overall aim of the reintroduction/translocation. Hence, if the intention were to establish a population that would be viable and self-sustaining in perpetuity, the island would need to be substantially larger than if the aim were to establish a low-management population that could be harvested to support other translocations.

Whilst there is a great deal of theory in relation to the appropriate area of habitat required to support a viable population of a species, there is a relative dearth of practical information on which to base such decisions. For *L. hirsutus,* such an assessment must, by necessity, be based on what is known from the existing populations of *L. hirsutus* which remain on islands, and on information derived from other translocation attempts such as the present program.

L. hirsutus presently occur on two islands, Bernier (4 267 ha) and Dorre (5 163 ha), and there are no records to indicate their historical occurrence on other islands. Thus the smallest island known to have supported the species has an area of approximately 4 200 ha. Short and Turner (1992) produced estimates of sizes of the mala populations for each island in 1988 and 1989: the populations on Bernier and Dorre Island were estimated as 2 600 and 1 700 respectively. To support the minimum viable population size of 500 individuals suggested by Franklin (1980), an island of similar productive capacity to Bernier would need to be about 850 ha., and to Dorre would need to be about 1 600 ha. These simplistic calculations significantly overestimate the area required, as both Bernier and Dorre Islands contain other species of similarly sized macropods, namely Burrowing Bettongs and Banded Hare-wallabies. They do, however, provide a crude guide to the size of islands required if the aim were to establish a viable self-sustaining population of mala.

Alternatively we can use the measures for total dispersion of the reintroduced population, derived from the present program, as a basis for estimating the area of habitat required to establish a viable population. As outlined in Chapter 6, the reintroduced population had an estimated mean dispersion of 252 ha that contained an average density of 6.65 mala. Using the two alternative hypotheses in relation to minimum viable populations which propose either 50 (Caughley & Sinclair 1994) or 500 (Franklin 1980), we derive estimated areas of 750 and 7500 ha respectively for establishment of a viable population of mala. As with the estimates based on known island populations, differences in both the level and patterning of productivity at sites will influence population dispersion, and hence the dispersion described from this study is a reflection of the manner in which this spinifex system satisfies the needs of the mala.

The next stage of the selection process involves identification of islands within the appropriate size class that are likely to have habitat conditions suitable to sustain mala. At the broad scale, this could be achieved by refining the selection process to include only islands that exist within the latitudes formerly occupied by mala, and within similar climatic zones. Based on projections of the species' former distribution and BIOCLIM analyses completed by Lundie-Jenkins (1989), this would include an area from the Pilbara south to Perth and several

South Australian islands east of the Great Australian Bight. Table 8.1 lists the islands within this area that meet both the size and climatic criteria. Of those listed, Enderby island is the only one that does not contain either introduced predators or another important rare native species.

Table 8.1

Offshore islands > 2000 ha in climatic zones similar to mala distribution

Island	Area (ha)	Exotic Species	Important native/ rare species	Management/tenure
Western Australia :				
West Lewis	1 974		*P. rothschildi*	translocated population
West Intercourse	2 300	cats & foxes	*P. rothschildi*	few survey data
Enderby	3 190			
Dolphin	3 281	foxes	*P. rothschildi, M. robustus & D. hallucatus*	regular fox control
Faure	5 148	cats		pastoral lease
Barrow	23 590		*I. auratus*	Oil exploration lease
Dirk Hartog	58 640	cats		pastoral lease
South Australia :				
Flinders	3 450	cats	*M. eugenii*(E)	
Saint Peter	3 731		*M. eugenii*(E), *B. penicillata*	introduced population
Thistle	4 113		*M. eugenii*(E), *P. lateralis*	lease for agriculture & tourism

In light of the limited options provided by a search with strict size restrictions, it would be necessary to consider smaller islands that could be used as captive breeding colonies until such time as larger islands or mainland sites became available. Suggesting a minimum size for such an island is difficult. Table 8.2 lists islands between 300 and 2000 ha that exist within the latitudes formerly occupied by mala, and within similar climatic zones. In Western Australia the best potential sites are Dixon Island and Trimouille Island, provided the cat and rat eradication program proceeds on the latter (Burbidge pers. comm.). Dixon is mostly sand; it is not reserved and is still under pastoral lease. Trimouille is all sand and is in the process of being returned from the Commonwealth to the state as a national park. The presence of cats and the time-frame for their removal may influence its availability as a translocation site. In South Australia possibilities seem to be Saint Peter, Thistle, Waldegrave and Eyre. Waldegrave is a conservation park near Eyre Peninsula, while Eyre is in the Nutys Archipelago, also a conservation park. No data on the geology or vegetation of these islands were available at the time of writing.

Table 8.2

Offshore islands > 300 ha but < 2000 ha in similar climatic zones to mala distribution

Island	Area (ha)	Exotic Species	Important native/ rare species	Management/tenure
Western Australia :				
East Wallabi	307		*M. eugenii*	
Delambre	320		*L. lakedownensis*	introduction planned
Middle	350		*I. auratus*	
Trimoulle	450	*R. rattus*, cats		plans to eradicate 94/95
Dixon	495		*M. robustus*	
Thevenard	520	*M. musculus*	*L. lakedownensis*	
West Wallabi	587		*M. eugenii*	
Gidley	798	cats		
Hermite	836	*R. rattus*, cats	*I. auratus*, *L. conspicillatus*	plans to eradicate reintroduction planned
Angel	927	cats & foxes		
East Lewis	1 018		*R. tunneyi*	
Garden	1 054		*M. eugenii*	
Depuch	1 121	foxes	*P. lateralis*	reintroduction planned
Rosemary	1 152		*P. rothschildi*	
Legendre	1 286	cats & foxes		
Rottnest	1 705	cats	*S. brachyurus*	
South Australia :				
Waldegrave	335		*R. fuscipes*	introduced
Reevesby	373		*L. conditor*	
Franklin	512		*L. conditor*, *I. obesulus*	
Saint Francis	809		*B. penicillata*	reintroduced
Boston	967		*M. eugenii*	introduced
Wedge	967		*P. lateralis*, *B. penicillata*	introduced
Eyre	984	cats	*R. fuscipes*	
Wardang	1 756			

Whilst they lie well outside the historical and bioclimatic range of the mala, the Sir Edward Pellew group of islands in the gulf region of the Northern Territory have also been suggested as potential translocation sites. The islands have strong affinities to the arid parts of central Australia and do harbour some mammal species that have disappeared from that region. (Johnson and Kerle 1991).

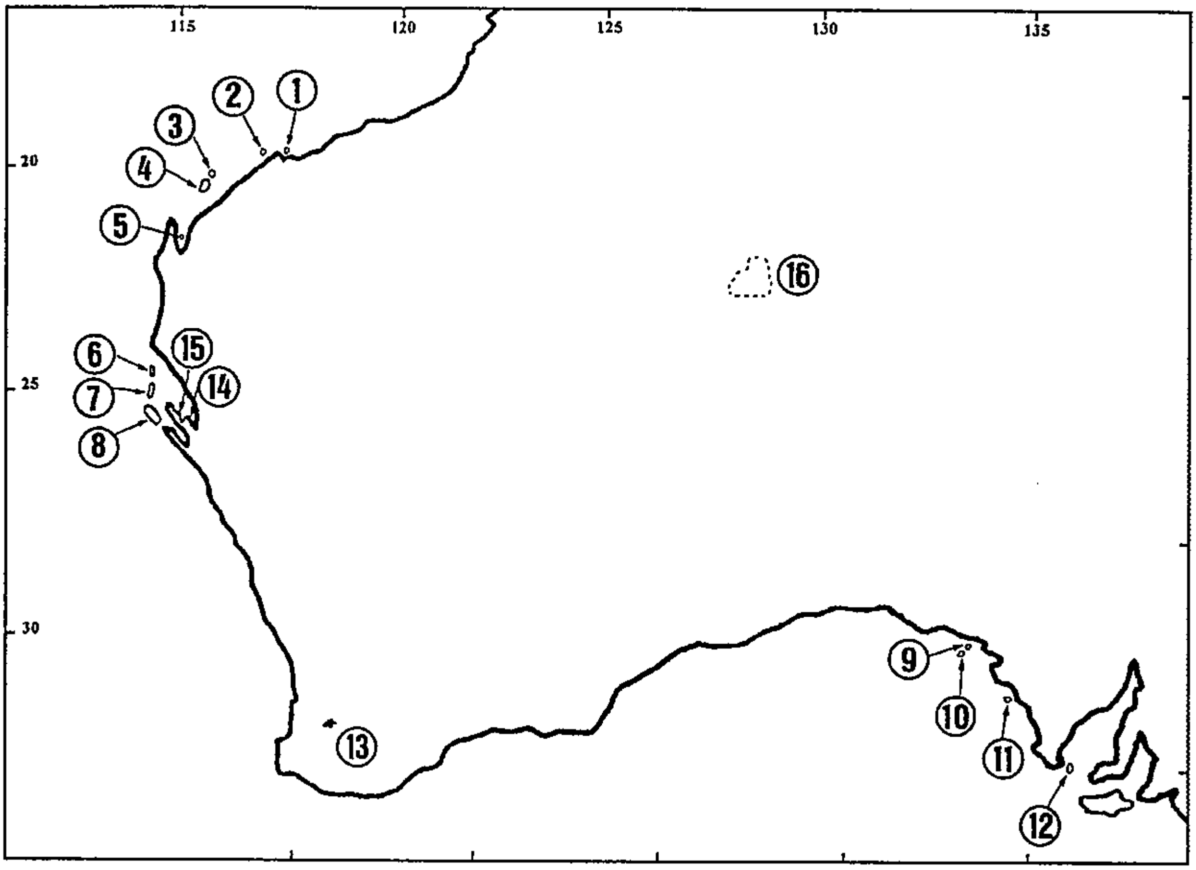


Figure 8.2 Location of alternative sites considered in relation to future translocation of mala. 1: Dixon Island 2: Enderby Island, 3: Trimouille Island, 4: Barrow Island, 5: Doule Island, 6: Bernier Island, 7: Dorre Island, 8: Dirk Hartog Island, 9: St Peter Island, 10: St Francis Island, 11: Waldegrave Island, 12: Thistle Island, 13: Dryandra Woodland, 14: Heirisson Prong, 15: Peron Peninsula, 16: Lake McKay.

Mainland Sites

Re-establishment of secure self-sustaining populations of mala on the mainland remains one of the major goals of the recovery plan for the species. Numerous options for translocation to securely managed or enclosed areas have been proposed bythe recovery team; these options are shown in Table 8.3. Both Heirisson Prong and Peron Peninsula are government-supported efforts involving the construction of predator-exclusion fences across narrow peninsulas of land near Shark bay in Western Australia.

Table 8.3
Potential mainland sites for future translocation of mala

Site name / state	Exotic Species	Important native/ rare species	Management/tenure
Northern Territory:			
Tanami Desert	Fox, cat, rabbit	Bilby, Mulgara	Aboriginal Freehold
Lake McKay Islands	Fox, cat, rabbit	Bilby ?	Aboriginal Freehold
Western Australia:			
Heirisson Prong	Predator exclusion fencing, rabbits	Burrowing Bettong, Western Barred Bandicoot, Shark Island Mouse	Leasehold : Useless Loop Community Biosphere project
Peron Peninsula	Predator exclusion fencing	Proposed reintroduction of 10+ species	National Park
Dryandra Forest	Extensive predator control, rabbits	Numbats, Woylies, Chuditch	National Park
South Australia:			
Yookamurra Sanctuary	Predator exclusion fencing, reported incursions.	Woylies, Boodies, Sticknest rats	Leasehold: Earth Sanctuaries Ltd.
New South Wales:			
Western Plains Zoo - BHP Sanctuary	Predator exclusion fencing	Numerous species	Leasehold: Zoological Trust of New South Wales
Scotia Sanctuary	Predator exclusion fencing	Numerous species	Leasehold: Earth Sanctuaries Ltd.

Current status of mala translocation program

Since completion of the detailed appraisal of translocation options, summarised in the preceding section, detailed investigations have commenced into the feasibility and suitability of both Trimouille Island and Dryandra Forest. Site inspections have been conducted in both areas by personnel from the Northern Territory Parks and Wildlife Commission and the Western Australian Department of Conservation and Land Management, and draft translocation proposals have been prepared (Langford & Burbidge pers. comm.) on behalf of the Mala Recovery Team. These proposals will be subject to both internal and external review of factors including habitat suitability, potential negative impacts, logistics, personnel and funding arrangements, and proposed transfer, release and monitoring protocols. Formal endorsement of these proposals by the external reviewers, and subsequent acceptance of these documents by the relevant government agencies could see translocations to these sites being implemented by the end of 1998. The relative success of these operations will have implications for decisions to proceed with other translocations of the species.

8.2.4 Lessons, improvements and future directions in planning and implementing the recovery plan

The processes of developing and implementing a recovery program have undergone significant evolutionary change since ANCA initiated its Endangered Species Program in 1992. A considerable amount has also been learned from actual involvement in the process as well as from the experiences of other recovery teams. The paragraphs below summarise some of the important operational questions that have been answered during the first five years of the Mala Recovery Program (1992-1997).

What comes first, the plan or the team ?

Many of the early recovery plans developed under the ESP, including the initial version of the recovery plan for the mala, were prepared in advance of any moves to establish an actual recovery team. As a consequence, this initial document represented only the views of the authors, and not those of a more broadly based recovery team. Since authorship of the mala recovery plan rested with a single agency, only limited information was included on resourcing, priority-setting and existing recovery efforts by other agencies. Subsequent revision of the recovery plan has benefited greatly from the diverse input of the recovery team. In addition, this team involvement has served to delegate responsibilities to team members and the agencies they represent. This increased "ownership" of the recovery plan should improve actual implementation of the plan. The process of developing a recovery plan should ideally be an interactive one, involving all major stakeholders. Logistics and the location of the extant populations will, however, frequently dictate that the major input to preparing a recovery plan will be borne by a single individual or small group.

Who should be on the team ?

During the initial formation of the mala recovery team significant concern was expressed about the size and composition of the team. The basis for selecting representatives for the team had implications for the development and implementation of the recovery plan. An initial criterion for determining membership of a recovery team would be based on the historic distribution of the species involved. However, for species with extensive continental distributions like the mala, this could lead to an unworkably large group. Whilst it is probably unreasonable to exclude organisations or individuals from involvement on the team, it is appropriate that they should be able to justify their position/involvement. Appointments based on purely political reasons, or as a form of "tokenism" do little to progress the recovery of a species, and may, in fact, hinder it. It is important that the recovery team is focussed and proactive, and not simply content to indulge in the process.

For species like the mala where recovery teams cover several states it may be appropriate to establish small individual state working groups to coordinate state actions and input into the planning and recovery process. The logistics of a central coordinator and broadly dispersed recovery team overseeing actual implementation of all actions make the formation of such working groups an important component of the recovery program.

What role do team members play ?

Potentially the greatest strength of a recovery team is the diverse range of skills and experiences it draws together. The task of realising this potential is not always easily achieved. Development of a recovery plan and formation of a recovery team serve to some extent to identify the responsibilities of organisations and individuals in relation to recovery actions. However, these actions alone do not specify the roles or duties of recovery team members, nor do they identify the skills these individuals bring to the team. It is clear that some attempt at defining roles and identifying team and individual skills would improve both the development and subsequent implementation of a recovery plan. Involvement of professional zoo-based staff and an independent publicist on the mala recovery team has led to significant improvements in the captive breeding and education/promotional aspects of the plan respectively.

How often should recovery teams meet ?

The frequency of meetings will differ considerably between recovery teams, principally as a function of both the geographic spread of their members and the types of actions being implemented. In the case of the mala recovery team, at least annual "whole" team meetings appear to be sufficient to report on implementation and revision of national actions. Smaller state-based working groups would benefit by more frequent meetings to discuss finer-grained technical aspects of local actions. As indicated in a previous section, teams must avoid indulging in the process of holding meetings without actually progressing species recovery. The majority of the people involved on the mala recovery team have significant work loads in addition to membership of the team. The sole criterion for determining the frequency of meetings should be the need to progress implementation and reporting of the recovery program. In some instances it will be appropriate to include costings within the recovery plan, covering travel expenses for key team members to attend meetings. This should only occur where their personal or organisational resources are insufficient to meet these costs, and their attendance is critical to advancing the recovery process.

How do we make sure it all goes according to "Plan" ?

Given that significant funding has been provided to the Mala Recovery Program on the basis of this original recovery plan it would seem, with the benefit of hindsight, that some form of external review of the plan prior to funding/implementation might have been appropriate. Such a review process could ensure that proposed actions are appropriate, scientifically valid and realistically costed. Whilst a recovery team will generally contain those people with the greatest experience and expertise in relation to a particular species, some form of external review ensures also that broader perspectives and alternative approaches are not overlooked. Many research and development corporations (Meat Research Council, Land and Water Resources Research and Development Corporation) have developed useful models for external review of programs.

The review process undertaken by the mala recovery team has shown the importance of the recovery plan being viewed as a dynamic document and not a static contract. To be effective, management of ecological systems and the species they contain must realistically be adaptable to changes in technology, species status, priorities and economics. Actions within a recovery plan that on review appear unlikely to return the desired benefits towards recovery of a species should be suspended or modified. The enormous expense of recovery programs, particularly for mammal species, dictates that an "adaptive management" approach be taken to species recovery. The most important elements of the recovery plan to facilitate this approach are clear measurable success/recovery criteria and regular internal review.

The mala recovery program, like other ANCA-supported recovery programs initiated in 1991, was subject to a major review during 1996. It is important that such reviews not be seen as adversarial but as an opportunity to develop and refine the recovery program to the ultimate benefit of the species. Like the initial review of the recovery plan, such reviews should involve people external to the recovery team. As an open and expected component of the recovery process they would lead to improvements in the development and implementation of recovery programs for the growing list of endangered Australian plants, animals and communities.

8.3 Evaluation of Rigorous Framework for Reintroductions

As should be the case with any models, the framework proposed in this thesis is intended to be a dynamic structure that is reviewed and modified through its application in real reintroduction programs. It is not intended to persist into perpetuity as the recipe for a successful reintroduction. It is only through the process of application and review that the appropriateness and representativeness of such models can effectively be evaluated. The remaining sections of this thesis will examine the framework originally proposed in Chapter 2, in light of its performance when applied in planning, testing and evaluation of the Mala reintroduction program. Included in this review will be suggestions for possible modifications to the model. As with other elements of the recovery process the framework will benefit by application and review by other persons external to its development. In conducting the introspective detailed in the following paragraphs, the author has attempted as far as possible to provide an impartial assessment of the relative strengths and weaknesses of the proposed framework.

8.3.1 Strengths of proposed framework

The rationale for developing a framework to model the reintroduction process, as originally detailed in Chapter 2, was that such an approach would assist managers and researchers:

- To define goals, problems and resources;
- To organise available information on a system or process;
- To assist in the interpretation of data;
- To communicate and test our understanding of a system or process; and
- To make predictions about systems or processes.

It is therefore appropriate that this rationale also be used as the basis for reviewing the usefulness of such an approach, and the benefits it could perceivably bring to the reintroduction process.

From the preceding sections of this thesis it is apparent that a properly planned reintroduction is not a singular management action, but a rather complex series of adaptive experiments. As a consequence, each reintroduction program provides an opportunity to learn from a unique set of conditions and potentials (Stanley-Price 1991). Whilst the ultimate goal of a reintroduction will be to re-establish a viable population of a species, a great many other things can be derived from a reintroduction that will benefit the recovery of a species. In order that this potential can be recognised it is important that a process of defining goals, problems and resources be incorporated in the planning of a reintroduction.

The Cognitive or Planning phase of the proposed framework provides a sound structure for pursuing such an approach, utilising the available body of knowledge on a species. Whilst such an approach may seem obvious, the evidence from many past reintroductions shows that a singular focus on the ultimate goal has often resulted in a poor understanding of the factors which have contributed to the success or failure of previous attempts (Copley 1995, Short *et al.* 1992). Recognition of the importance of such pre-planning and goal setting has seen the recent development and adoption of a formal translocation proposal process by organisations such as the

IUCN (International Union of Conservation Nations) and ANZECC (Australian and New Zealand Environment and Conservation Council). It is apparent, from the available reviews of past reintroductions and from the present study, that clearly defining the goals, problems and resources will:

- enhance the quality and hence interpretation of information obtained from a reintroduction,
- provide a sounder basis for measuring milestones within the reintroduction process, and
- increase the probability of achieving a successful reintroduction.

The strengths which exist in the Cognitive or Planning Phase also have flow-on effects into the Experimental Phase of the reintroduction framework. Whilst it will almost always prove impossible to comprehensively research all the elements of a reintroduction, a structured approach provides a sounder basis for interpreting information derived from a reintroduction. This, in turn, improves the ability of managers and researchers to understand the reintroduction process, and hence to make predictions about reintroductions involving different sites or species. Copley's (1995) review of early translocations of native vertebrates in South Australia shows that poorly planned and monitored reintroductions, whether they successfully established populations or not, contribute little to our understanding of the reintroduction process. The high costs usually associated with reintroduction programs for vertebrate species demand that far greater return be generated from this investment. The ability to interpret and extrapolate the results of one reintroduction attempt to other future attempts represents better value for money compared with the trial and error approach adopted in some programs of the past.

8.3.2 Weaknesses of proposed framework

To some managers and researchers the adoption of a generic or structured approach will undoubtedly be viewed as unnecessarily restrictive, and as a disincentive to innovation or the adoption of novel approaches to reintroduction. The framework promotes a logical stepwise approach to reintroductions whereby the process is refined through adaptive management. Whilst this may be a slightly conservative approach, it ensures that new ideas do not ignore bodies of past knowledge and, in fact, build onto them. Clearly where a species' status becomes critical, novel approaches will be demanded by the urgency of the situation.

Provided such programs are planned and implemented in a structured way they too can also contribute to our understanding of a species and its recovery, irrespective of their ultimate fate.

The opposite criticism could also be directed at the proposed framework, whereby the adaptive management approach promoted by the model, with protocols modified according to monitored outcomes, could be seen as a compromise of the scientific method. Whilst a rigorous scientific approach is favoured, adherence to these principles will often be tempered by realism and practicality (Stanley-Price 1991). When working with endangered species, experimental design principles such as replication, sample size and statistical significance must often be compromised due to factors such as small source populations and limited secure potential release sites, as well as economic and logistical constraints. Unfortunately, the failure to strictly adhere to many of these experimental design principles may account for the large number of reintroductions which remain unpublished or undocumented. Growing recognition of adaptive management as a legitimate approach to wildlife management will ensure that an increased number of future reintroductions are reported in the literature, despite their experimental shortcomings.

In applying the current framework to the mala reintroduction it is apparent that the current structure is biased towards the biological and technical aspects of reintroduction. There is no recognition of the potential for economics or logistics to interfere with, or influence, the direction of a reintroduction program, implicit within the framework. Circumstances may arise where management actions or decisions that are favoured or suggested on purely biological grounds may be impossible to implement, due to economic or logistical constraints. Whilst it may not be explicit within the framework it is recognised as reality, and will invariably influence the direction in which a reintroduction proceeds.

The passage of a source population through a series of population states towards a self-sustaining reintroduced population, depicted in the framework, is biased towards mammals. The structure could, however, be easily adapted to reflect passage through life cycles relevant to any other taxa group, without fundamentally compromising the intent of the framework. Application of the framework to other species, including other vertebrates, invertebrates and plants will ultimately serve as a means of testing its structure, and hopefully lead to refinements which enhance its effectiveness in assisting in the planning, implementation, interpretation and evaluation of reintroductions.

In constructing the model, no attempt was made to incorporate decision rules or criteria which would direct a reintroduction's passage through the model. This was not to imply that such criteria are not important, but in recognition of the differences that will exist in such criteria between different species, localities and social settings. For different species' attributes like age-specific reproductive and survival rates, age of first breeding, sex and age structure, breeding and social system will all influence the rate at which they pass through the population states described by the framework. Establishing criteria to measure the progress of a reintroduced population towards a viable self-sustaining population will be important in both measuring the success of a program, and in identifying factors impacting on a population's establishment. Clarke (1996) has also suggested that all recovery programs require some form of "escape clause", which could be used to halt a program if there was little or no-likelihood of the action improving the recovery process. The triggers for such an "escape clause" could include: continuing decline in the release population over a set time period, loss/death of a predetermined proportion of the population, lack of natural recruitment to the population over a set time period, or a requirement for unsustainable management input into the system over a set time period. In the case of the mala program reported in this thesis, the combined influence of low pouch-young survival rates and high episodic losses of animals to predation triggered the decision to cease releases at the Sangster's Bore site.

8.3.3 Multi-species reintroductions and fauna reconstruction sites

One of the particular advantages of applying a rigorous framework to reintroductions, highlighted in section 8.3.1, is that it provides greater potential for extrapolating the results derived from a program conducted on one species to future work on other species. The body of knowledge derived from a well-planned reintroduction can provide a sound basis for planning and implementing reintroductions for related species or habitats. Current trends within Australia towards multi-species reintroductions and establishment of so called "Fauna Reconstruction Zones", whilst essentially driven by economies of scale, could presumably therefore benefit by adopting a structured approach. Such programs seek to coordinate re-establishment for suites of species at particular strategic locations with the ultimate aim of sequentially reconstructing the previously recorded fauna. Utilising a structured approach to such programs would provide a sound basis for improving the success of the re-establishment process by testing and refining techniques. Without such an approach, the outcomes of one reintroduction attempt would provide little in the way of reliable information for planning future releases of the same or different species.

8.4 General conclusions

The Critically Endangered status of the mala (IUCN 1994) ensures that there will be an ongoing recovery effort for the species. A wealth of management-related information has been derived that will be used to formulate management plans and to determine future directions. The final decision on these and other options for the species will rest with the recovery team. The prime objective in the short term will be to improve the status of the mala, and hence provide more opportunity to investigate higher risk options for re-establishing the species. The current Critically Endangered status for the species, with numerically small and geographically limited populations, dictates that our current approach be relatively conservative.

As stated in the introduction to this chapter, the fact that there are no remaining known wild populations of mala guarantees that reintroduction will continue to be a key component in their recovery. The poor record of Australia's arid zone in relation to mammal declines and extinctions further ensures that the application of reintroduction as a conservation strategy is only likely to increase in the future. It is, however, equally apparent that the reintroduction process still requires further refinement. The results of the study presented in this thesis clearly show the benefits which can be derived from a structured approach to reintroduction. Only by adopting a rigorous approach to reintroductions will it be possible to refine and adjust this important adaptive management process, such that the outcomes from any reintroduction extend beyond the species and the sites involved in a particular release program.

REFERENCES

Abbott, I. and Burbidge, A.A. (1995). The occurrence of mammal species on the islands of Australia: a summary of existing knowledge. CALMScience **1**(3): 259-324.

Agar, N.S. and Godwin, I.R. (1991). Red cell metabolism in the Brown Antechinus the Bilby and the Rufous Hare-wallaby. Australian Journal of Zoology **39**: 681-687.

Algar, D. (1986). An ecological study of macropodid marsupial species on a reserve. Ph.D. thesis, University of Western Australia, Perth.

Amlander, C.J. and MacDonald, D. (1979). A handbook of biotelemetry and radio tracking. Oxford Pergamon Press, New York.

Armstrong, D.P., Soderquist, T. and Southgate, R. (1995). Designing experimental reintroductions as experiments. From: Reintroduction Biology of Australasian and New Zealand Fauna. Ed. M. Serena. Surrey Beatty and Sons, Sydney.

Aslin, H.J. (1983). Marsupials in the arid zone. From: What future for Australia's Arid Lands?. Ed(s). J.Messer and G. Mosely. Australian Conservation Foundation, Sydney.

Australian Bureau of Meteorology, Monthly Weather Review, N.T.

Baker, B.R. (1982). Migration: Paths through space and time. Hodder and Stoughton, London.

Ballou, J. and Ralls, K. (1982). Inbreeding and juvenile mortality in small populations of ungulates: A detailed analysis. Biological Conservation **24**: 239-272.

Ballou, J. (1995). An overview of small population biology. From: Vortex: A stochastic simulation of the extinction process, Version 7 User's Manual. Ed(s) R.C. Lacy, K.A. Hughes & P.S. Miller. IUCN/SCC Conservation Breeding Specialist Group, Apple Valley, MN, USA.

Beck, B. B., Rapaport, L.G., Stanley-Price, M.R. and Wilson, A.C. (1994). Reintroduction of captive-born animals. From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner. Chapman and Hall, London.

Belbin, L. (1990). The analysis of pattern in bio-survey data. From: Nature Conservation: Cost effective biological surveys and data analysis. Ed(s). C.R. Margules and M.P. Austin. Commonwealth Scientific and Industrial Research Organisation, Canberra.

Belbin, L. (1995). PATN - Pattern analysis package: Technical Reference. Commonwealth Scientific and Industrial Research Organisation, Division of Wildlife and Ecology, Canberra.

Berman, D. and Jarman, P.J. (1987). Feral horses in the Northern Territory. Volume 1: Ecology of Feral Horses in central Australia and their interaction with cattle, Unpublished report to the Conservation Commission of the Northern Territory.

Berman, D. (1991). A simple method for illustration of trends in rainfall surplus or deficiency during ecological studies of mammals in arid areas. Newsletter of the Australian Mammal Society. Autumn.

Blake, D.H., Hodgson, I.M. and Muhling, P.C. (1979). Geology of the Granites-Tanami region, Northern Territory and Western Australia. Bureau of Mineral Resources Bulletin.

Bolton, B.L. and Latz, P.K. (1978). The Western Hare-Wallaby *Lagorchestes hirsutus* (Gould) (Macropodidae), in the Tanami Desert. Australian Wildlife Research 5, 285-293.

Boulanger, J.G. and White, G.C. (1990). A comparison of home-range estimators using monte carlo simulation. Journal of Wildlife Management **54**: 310-315.

Bridie, A., Hume, I.D. and Hill, D.M. (1994). Digestive-tract function and energy requirements of the Rufous Hare-wallaby *Lagorchestes hirsutus*. Australian Journal of Zoology **42**: 761-774.

Broughton, S.K. and Dickman, C.R. (1991). The effect of supplementary food on home range of the Southern Brown Bandicoot, *Isoodon obesulus* (Marsupialia: Peramelidae). Australian Journal of Ecology **16**: 71-78.

Burbidge, A.A. and Johnson, K.A. (1983). Rufous Hare-wallaby. From: The Australian Museum Complete Book of Australian Mammals. Ed. R. Strahan. Angus and Robertson, Sydney.

Burbidge, A.A., Johnson, K.A., Fuller, P.F. and Southgate, R.I. (1988). Aboriginal knowledge of the mammals of the central deserts of Australia. Australian Wildlife Research **15**: 9-39.

Burbidge, A.A. and McKenzie, N.L. (1983). Wildlife of the Great Sandy Desert Western Australia. Wildlife Research Bulletin No 12, Western Australian Department of Fisheries and Wildlife, Perth.

Burbidge, A.A. and McKenzie, N.L. (1989). Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. Biological Conservation **50**: 143-198.

Burbidge, A.A. and Pearson, D.J. (1988). A search for the Rufous Hare-wallaby and other rare mammals in the Great Sandy and Little Sandy Deserts, Western Australia. Wildlife Research Bulletin, Department of Conservation and Land Management, Perth.

Carbyn, L.N., Armbruster, H.J. and Mamo, C. (1994). The Swift Fox reintroduction program in Canada from 1983 to 1992. From: Restoration of Endangered Species. Ed(s) M.L. Bowles and C.J. Whelan, Cambridge University Press, London.

Caughley, G. (1966). Mortality patterns in mammals, Ecology **47**: 906-918.

Caughley, G. (1980). Analysis of Vertebrate Populations. John Wiley and Sons, Brisbane.

Caughley, G. (1994). Directions in conservation biology. Journal of Animal Ecology **63**: 215-224

Caughley, G. and Gunn, A. (1996). Conservation Biology in Theory and Practice, Blackwell Science, Cambridge.

Caughley, G. and Sinclair, A.R.E. (1994). Wilflife Ecology and Management, Blackwell Science, Cambridge.

Christensen, P.E.S. (1980). The biology of *Bettongia penicillata* (Gray 1837) and *Macropus eugenii* (Desmarest 1917) in relation to fire. Forests Department Western Australia Bulletin No. 91, Perth.

Christensen, P.E.S. and Burrows, N. (1995). Project Desert Dreaming: the reintroduction of mammals to the Gibson Desert. From: Reintroduction Biology of Australasian and New Zealand Fauna. Ed. M. Serena. Surrey Beatty and Sons, Sydney.

Clancy, T.F. and Croft, D.B.(1992). Population dynamics of the Common Wallaroo (*Macropus robustus erubescens*) in Arid New South Wales, Wildlife Research **19**: 1-16.

Clarke, T. W. (1996). Appraising threatened species recovery processes: Some pragmatic recommendations for improvements. From: Back from the Brink: Refining the threatened species recovery process. Ed(s). S. Stephens and S. Maxwell, Surrey Beatty and Sons, Sydney

Clutton-Brock, T.H., Albon, S.D. and Guiness, F.E. (1982). Competition between female relatives in a matrilocal mammal. Nature **300**: 178-180.

Cockburn, A., Scott, M.P. and Scotts, D. (1985). Inbreeding avoidance and male-biased dispersal in *Antechinus* spp. (Marsupialia: Dasyuridae). Animal Behaviour 33: 908-915.

Cole, J.R., Langford, D.G. and Gibson, D.F. (1994). Capture myopathy in *Lagorchestes hirsutus* (Marsupialia: Macropodidae). Australian Mammalogy 17: 137-139.

Cooke, B.D. (1982). Reduction of food intake and other physiological responses to a restriction of drinking water in captive wild rabbits, *Oryctolagus cuniculus* (C.). Australian Wildlife Research 9: 247-252.

Copley, P.B. (1995). Translocations of native vertebrates in South Australia: a review. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

Courtney, J. (199).Taxonomy and biogeography of *Lagorchestes hirsutus* and *Lagorchestes leporides* . Bulletin of Australian Mammal Society

Courtney, J. (1993). The systematics of the Rufous Hare-wallaby *Lagorchestes hirsutus* (Gould 1844). Sixth International Theriological Congress University of New South Wales, Sydney.

Croft, D.B. (1989). Social organisation of the macropodoidea. From: Kangaroos, Wallabies and Rat-Kangaroos. Ed(s). G. Grigg, P.J. Jarman and I.D. Hume, Surrey Beatty and Sons, Sydney.

Dawson, T.J. and Hulbert, A.J. (1970) Standard metabolism, body temperature and surface areas of Australian marsupials. American Journal of Physiology 218: 1233-1238

De Bois, H.,Dhondt, A.A. and Van Puijenbroeck, B. (1990). Effects of inbreeding on juvenile survival of the Okapi *Okapia johnstoni* in captivity. Biological Conservation 54: 147- 155

Delaney, R. (1993). Life history and reproductive ecology of a tropical rock wallaby, *Petrogale assimilis*. Ph.D. Thesis, James Cook University, Townsville, Australia.

Dickman, C.R. (1996). Incorporating science into recovery planning for threatened species. From: Back from the Brink: Refining the threatened species recovery process. Ed(s). S. Stephens and S. Maxwell, Surrey Beatty and Sons, Sydney

Duffy, A.C., Seebeck, J.H., McKay, J. and Wilson, A.J. (1995). Reintroduction of the Eastern Barred Bandicoot *Perameles gunnii* at Gellibrand Hill Park, Victoria. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

Ealey, E.H.M., Bentley, P.J. and Main, A.R. (1965). Studies on water metabolism of the hill kangaroo *Macropus robustus* (Gould) in northwest. Australia. Ecology **46**: 473-479.

E.S.P. (1995). Recovery Plan Guidelines for endangered and vulnerable species and endangered ecological communities. Endangered Species Unit, Australian Nature Conservation Agency, Canberra.

E.S.A.C. (1995). Policy for translocations of vertebrate animals in Australia. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Chipping Norton.

E.S.R.I. (1992). ArcInfo. Starter Kit: Users Guide Version 3.4D plus.

Finlayson, H.H. (1935). The Red Centre: Man and Beast in the heart of Australia. Angus and Robertson, Sydney.

Finlayson, H.H. (1943). A new species of *Lagorchestes*. (Marsupialia) Records of the South Australian Museum **67**: 319-321.

Finlayson, H.H. (1961). On central Australian mammals. Part IV. The distribution and status of central Australian species. Records of the South Australian Museum **14**: 141-191.

Frankel, O.H. (1982). The role of conservation genetics in the conservation of rare species. From: Species at Risk: Research in Australia. Proceedings of a symposium on the biology of rare and endangered species in Australia. Ed(s) R.H. Groves and W.D.L. Ride, Australian Academy of Science, Canberra.

Frankel, O.H. and Soule, E. (1981). Conservation and Evolution. Cambridge University Press, New York.

Frankham, R., Hemmer, H., Ryder, O.A., Cothran, E.G., Soule, M.E., Murray, N.D. & Snyder, M. (1986). Selection in captive populations. Zoo Biology **5**: 127-138.

Franklin, I.R. (1980). Evolutionary change in small populations. From: Conservation Biology: An evolutionary - Ecological Perspective, Ed(s) M.E. Soule and B.A. Wilcox, Sinauer Associates, Sunderland.

Friend, J.A.(1990). The numbat *Myrmecobius fasciatus* (Myrmecobidae) history of decline and potential for recovery. Proceedings of the Ecological Society of Australia **16**: 369-377.

Friend, J.A. and Thomas, N.D. (1994). Reintroduction and the numbat recovery programme. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

Gibson, D.F. (1986). A biological survey of the Tanami Desert in the Northern Territory. Conservation Commission of the Northern Territory. Technical Report No. 30, 1-258.

Gibson, D.F., Lundie-Jenkins, G., Langford, D.G., Cole, J.R., Clarke, D.E. & Johnson, K.A. (1994). Predation by Feral Cats *Felis catus* on the Rufous Hare-wallaby *Lagorchestes hirsutus* in the Tanami Desert. Australian Mammalogy **17**: 103-108.

Gibson, D.F., Johnson, K.A., Langford, D.G., Cole, J.R., Clarke, D.E. and Willowra Community (1995). The Rufous Hare-wallaby *Lagorchestes hirsutus*: a history of experimental reintroduction in the Tanami Desert, Northern Territory. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

Gould, J. (1844) Descriptions of three new species of *Halmaturus* and *Lagorchestes*. Proceedings of the Zoological Society of London **XII**: 31-32.

Green, B. (1989). Water and energy turnover in free-living macropodoids. From: Kangaroos, Wallabies and Rat-Kangaroos. Ed(s). G. Grigg, P.J. Jarman and I.D. Hume, Surrey Beatty and Sons, Sydney.

Griffin, G.F. (1985). Manual for collection and analysis of data for fire behaviour predictions : Applications of a fire management strategy at Uluru National Park. C.S.I.R.O. Division of Wildlife and Rangelands Research. Technical Memo.No. 22.

Griffin, G.F.(1990). Characteristics of three spinifex communities in Central Australia. Journal of Vegetation Science **1**: 435-444.

Griffith, B., Scott, J.M., Carpenter, J.W. and Read, C. (1989). Translocation as a species conservation tool: status and strategy. Science **245**: 477-480.

Holling, C.S. (1978). Adaptive environmental assessment and management. International Series on Applied Systems Analysis 3, International Institute for Applied Systems Analysis. John Wiley and Sons, Toronto, Canada.

Howard, W.E. (1960). Innate and environmental dispersal of individual vertebrates. American Midland Naturalist **63**: 152-161

I.U.C.N. (1987). The IUCN position statement on translocation of living organisms, Introductions, reintroductions and re-stocking, IUCN, Gland, Switzerland.

I.S.I.S. (1995). Single Populations and Record Keeping Systems: Users Manual Version 1.3 International Species Information Systems, Apple Valley, U.S.A.

Jarman, P.J. (1994). The eating of seedheads by species of Macropodidae. Australian Mammalogy **17**: 51-63.

Jarman, P.J. and Brock, M.A. (1996) Collaboration of science and management in endangered species recovery. From: Back from the Brink: Refining the threatened species recovery process. Ed(s). S. Stephens and S. Maxwell, Surrey Beatty and Sons, Sydney

Jarman, P.J. and Phillips, C.M. (1989). Diets in a community of macropod species. From: Kangaroos, Wallabies and Rat-kangaroos, Ed(s) G. Grigg, P.J. Jarman, I.D. Hume. Surrey Beatty and Sons, Sydney.

Johnson, C.N. (1988). Dispersal and sex ratio at birth in primates. Nature **332**: 726-728.

Johnson, C.N. (1989). Dispersal and philopatry in the macropodoids. From: Kangaroos, Wallabies and Rat-kangaroos, Ed(s) G. Grigg, P.J. Jarman, I.D. Hume. Surrey Beatty and Sons, Sydney.

Johnson, K.A. (1980). Spatial and temporal use of habitat by the Red-necked Pademelon *Thylogale thetis* (Marsupialia: Macropodidae). Australian Wildlife Research **7**: 157-166

Johnson, K.A. (1988). Rare and Endangered: Rufous Hare-wallaby. Australian Natural History **22**: 406-407.

Johnson, K.A., Burbidge, A.A. and McKenzie, N.L. (1989). Australian macropodoidea: status, causes of decline and future research and management. From: Kangaroos, Wallabies and Rat-Kangaroos. Ed(s). G. Grigg, P.J. Jarman and I.D. Hume, Surrey Beatty and Sons, Sydney.

Johnson, K.A., Gibson, D.F., Langford, D.G. and Cole, J.R. (1995).Recovery of the Mala *Lagorchestes hirsutus*: a 30-year unfinished journey. From: Back from the Brink: Refining the threatened species recovery process. Ed(s). S. Stephens and S. Maxwell, Surrey Beatty and Sons, Sydney.

Johnson, K.A. and Kerle, J.A. (1991). Flora and vertebrate fauna of the Sir Edward Pellew Group of islands, Northern Territory. A report to the Australian Heritage Commission. CCNT:Alice Springs.

Johnson, K.A. and Lundie-Jenkins, G. (1992). Recovery Plan for the Mala, *Lagorchestes hirsutus*. A report to the Endangered Species Program of the Australian Nature Conservation Agency, Canberra.

Kenward, R.E. (1987). Wildlife Radio Tagging. Academic Press. San Diego CA.

Kenward, R.E. (1990). Ranges IV: Software for analysing animal location data. Institute of Terrestrial Ecology, Wareham, United Kingdom.

Kinnear, J.E., Bromilow, R.N., Onus, M.L. and Sokolowski, R.E.S. (1988). The Bromilow Trap: a new risk free soft trap suitable for small to medium sized macropodids. Australian Wildlife Research **15**: 235-237.

Kitchener, D.J. (1973). Notes on home range and movement in two small macropods, the Potoroo (*Potorous apicalis*) and the Quokka (*Sentonix brachyurus*) Mammalia **37**: 231-240.

Kleiman, D.G. (1989). Reintroduction of captive mammals for conservation. Bioscience **39**: 152-161.

Kleiman, D.G., Beck, B.B., Dietz, J.M. and Dietz, L.A. (1991). Costs of a reintroduction and criteria for success: accounting and accountability in the Golden Lion Tamarin conservation program: From: Beyond Captive Breeding: Reintroducing endangered mammals to the wild. Zoological Society of London Symposia 62, Ed. J.H.W. Gipps, Oxford Science Publications, Oxford.

Kleiman, D.G., Stanley-Price, M.R. and Beck, B.B. (1994). Criteria for reintroductions. From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner. Chapman and Hall, London.

Kock, R.A. and Woodford, M.H. (1988). Reintroduction of Pere David's Deer (*Elaphurus davidianus*), Scimitar-horned Oryx (*Oryx dammah*) and the Arabian Oryx (*Oryx leucoryx*) to their native habitats - a veterinary perspective. From: Proceedings of Joint Conference American Zoological Veterinarians and American Association of Wildlife Veterinarians,Toronto, Ontario.

Lacy, R.C. and Clarke, T.W. (1990). Population viability Assessment of the Eastern Barred Bandicoot in Victoria. From: Management and Conservation of Small Populations. Ed(s). T.W. Clark and J.H. Seebeck, Chicago Zoological Society, Brookfield.

Lasley, J.F. (1978). Genetics of livestock improvement. Prentice-Hall, Englewood Cliffs.

Leberg, P.L. (1991). Strategies for population reintroduction: Effects of genetic variability on population growth and size. Conservation Biology 7: 194-199.

Lifson, N. and McClintock, R. (1966). Theory of use of the turnover rates of body water for measuring energy and material balance. Journal of Theoretical Biology **12**: 46-74.

Lindenmyer, D. (1995). Some ecological considerations and computer-based approaches for the identification of potentially suitable release sites for reintroduction programs. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

Loorhan, C. (1985). The Warlpiri and the Rufous Hare-wallaby. Habitat **13**: 8-9.

Lundie-Jenkins, G. (1989). The ecology and management of the Rufous Hare-wallaby *Lagorchestes hirsutus* in the Tanami Desert. Unpublished M.Res.Sci. Thesis, University of New England, Armidale.

Lundie-Jenkins, G. (1993). Reproduction and growth to sexual maturity in the Rufous Hare-wallaby *Lagorchestes hirsutus* Gould, (Marsupialia: Macropodidae) in captivity. Australian Mammalogy **16**: 45-49.

Lundie-Jenkins, G. (1993). Observations on the behaviour of the Rufous Hare-wallaby *Lagorchestes hirsutus* Gould, (Marsupialia: Macropodidae) in captivity. Australian Mammalogy **16**: 29-34.

Lundie-Jenkins, G. (1993). Ecology of the Rufous Hare-wallaby, *Lagorchestes hirsutus* Gould (Marsupialia: Macropodidae) in the Tanami Desert, N.T. I. Patterns of habitat use and preference . Wildlife Research **20**: 457-476.

Lundie-Jenkins, G., Phillips, C.M. and Jarman, P.J. (1993). Ecology of the Rufous Hare -wallaby, *Lagorchestes hirsutus* Gould (Marsupialia: Macropodidae) in the Tanami Desert, N.T. II. Diet and feeding strategy. Wildlife Research **20**: 477-494.

Lundie-Jenkins, G., Corbett, L.K. and Phillips, C.M.(1993). Ecology of the Rufous Hare -wallaby, *Lagorchestes hirsutus* Gould (Marsupialia: Macropodidae) in the Tanami Desert, N.T. III. Interactions with introduced mammal species. Wildlife Research **20**: 495-511.

Lundie-Jenkins, G. and Bellchambers, K. (1995). Reintroduction of the Rufous Hare-wallaby into Aboriginal Land in the Lander River region of the Tanami Desert, Northern Territory, Northern Territory Parks and Wildlife Commission, Alice Springs.

Magin, C.D., Johnson, T.H., Groombridge, B. Jenkins, M. & Smith, H. (1994). Species extinctions, endangerment and captive breeding. From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner. Chapman and Hall, London.

Masters, P. (1993). The effects of fire-driven succession and rainfall on small mammals in spinifex grasslands at Uluru National Park, Northern Territory. Wildlife Research **20**: 803-813.

Maxwell, S., Burbidge, A.A. and Morris, K. (1996). The Action Plan for Australian Marsupials and Monotremes. IUCN/SSC Australasian Marsupial and Monotreme Specialist Group,Canberra.

May, R.M. (1991). The role of ecological theory in planning re-introduction of endangered species. From: Beyond Captive Breeding: Reintroducing endangered mammals to the wild. Zoological Society of London Symposia 62, Ed. J.H.W. Gipps, Oxford Science Publications, Oxford.

Mazzer, T.M. (1988). Relationships between soils and hummock grassland communities in the Tanami Desert. Unpublished Bachelor of Natural Resources Thesis, University of New England, Armidale.

McCallum, H. (1995). Modelling translocation strategies for the Bridled Nailtail Wallaby, *Onychogalea fraenata* Gould, 1840. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty and Sons, Sydney.

McCallum, H., Timmers, P. and Hoyle, S. (1995). Modelling the impact of predation on reintroductions of Bridled Nailtail Wallabies. Wildlife Research **22**: 163-171.

McDonald, P., Edwards, r.a. and Greenhalgh, J.F.D. (1982). Animal Nutrition Third Edition Longman, New York.

McFarlane, W.V.(1968). Adaptations of ruminants to tropics and deserts. From: The Adaptation of Domestic Animals, Ed, E.S.E. Hafez, Lea and Febiger, Philadelphia.

McLean, I.G., Lundie-Jenkins, G., Jarman, P.J. and Kean, L. (1993). Copulation and associated behaviour in the Rufous hare-wallaby, *Lagorchestes hirsutus*. Australian Mammalogy **16**: 77-79.

McLean, I.G., Lundie-Jenkins, G. and Jarman, P.J. (1994). Training captive Rufous Hare -wallabies to recognise predators. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena. Surrey Beatty & Sons, Sydney.

McLean, I.G., Lundie-Jenkins, G. and Jarman, P.J. (1995). Teaching an endangered mammal to recognise predators. Biological Conservation **75**: 51-62.

Menkhorst, K. and Mansergh, I. (1977). Report on the mammalian fauna of the South Gippsland Study Area (District 2). National Museum of Victoria, Melbourne.

Moore, D.E. and Smith, R. (1991). The Red Wolf as a model for carnivore reintroductions. From: Beyond Captive Breeding: Reintroducing endangered mammals to the wild. Zoological Society of London Symposia 62, Ed. J.H.W. Gipps, Oxford Science Publications, Oxford.

Moritz, C., Worthington Wilmer, J., Pope, L., Sherwin, W.b., Taylor, A.C. and Limpus, C.J. (1996) Applications of genetics to the conservation and management of Australian Fauna: Four case studies from Queensland (in press).

Morton, S.R. (1984). The effects on native animals of succession driven by fire. unpublished preschedule. CSIRO Division of Wildlife and Ecology, Alice Springs.

Morton, S.R. (1990). The impact of European settlement on the vertebrate animals of arid Australia: A conceptual model. Proceedings of the Ecological Society of Australia **16**: 201-213.

Nagy, K.A. (1980). CO_2 production in animals, analysis of potential errors in the doubly labelled water method. American Journal of Physiology **238**: R466-473.

Nagy, K.A. and Martin, A.W. (1985). Field metabolic rate, water flux, food consumption time budgets of Koalas, *Phascolarctos cinereus* (Marsupialia Phascolarctidae) in Victoria. Australian Journal of Zoology. **33**: 655-665.

Newsome, A.E. (1965). Reproduction in natural populations of the Red Kangaroo, *Megaleia rufa* (Demarest), in central Australia. Australian Journal of Zoology **13**: 735-59.

Newsome, A.E.(1971). Competition between wildlife and domestic livestock. Australian Veterinary Journal **47**: 577-586.

Owen-Smith, R.N. (1993). Comparative mortality rates of male and female kudus: the costs of sexual size dimorphism. Journal of Animal Ecology **62**: 428-440.

Parker, S.A. (1973). An annotated checklist of the native land mammals of the Northern Territory. Records of the South Australian Museum **16**: 1-57.

Peterson, C.C., Nagy, K.A. and Diamond, J. (1990). Sustained metabolic scope. Proceedings of the National Academy of Science, U.S.A. **87**: 2324-2328.

Pearson, D.J. (1989). The diet of the Rufous Hare-wallaby (Marsupialia: Macropodidae) in the Tanami Desert. Australian Wildlife Research **16**: 527-37.

Perry, J., Bridgewater, P.D. and Horseman, D.L. (1973). Captive propagation: a progress report. Zoologica 57(3): 109-117.

Pinder, N.J. and Barkham, J.P. (1978). An assessment of the contribution of captive breeding to the conservation of rare mammals. Biological Conservation **13**: 187-245.

Pollock, K.H., Winterstein, S.R., Bunck, C.M. and Curtis, P.D. (1989). Survival analysis in telemetry studies: The staggered entry design. Journal of Wildlife Management **53**: 7 -15.

Pope, L.C., Sharp, A. and Moritz, C. (1996). Population structure of the Yellow-footed Rock Wallaby, *Petrogale xanthopus* inferred from mtDNA sequences and microsatellites. Molecular Ecology (in press).

Possingham, H. (1996). Risk and uncertainty: mathematical model and decision making in conservation biology. From: Conservation Biology. Ed. I.F. Spellerberg, Longman, Singapore.

Ralls, K. and Ballou, J. (1982). Effect of inbreeding on juvenile mortality in some small mammal species. Laboratory Animals **16**: 159-166.

Ralls, K. and Ballou, J. (1983). Genetic diversity in California Sea Otters: Theoretical considerations and management implications. Biological Conservation **25**: 209-232.

Ralls, K., Brugger, K. and Ballou, J.(1979). Inbreeding and juvenile mortality in small populations of ungulates. Science **206**: 1101-1103.

Ride, W.D.L. and Tyndale-Biscoe, C.H. (1962). Mammals. From: The results of an expedition to Bernier and Dorre Islands, Shark Bay, Western Australia in July 1959. Ed. Frazer, A.J., Fauna Bulletin No. 2, Western Australian Fisheries Department.

Serena, M. (1995) Reintroduction biology of Australian and New Zealand Fauna. Surrey Beatty & Sons, Sydney.

Sheperdson, D. (1994). The role of environmental enrichment in the captive breeding and reintroduction of endangered species. From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner.Chapman and Hall, London.

Short, J., Bradshaw, S.D., Giles, J., Prince, R.I.T. and Wilson, G. (1992). The reintroduction of macropods (Marsupialia: Macropodidae) in Australia - a review. Biological Conservation **62**: 189-204.

Short, J. and Turner, B. (1992) The distribution and abundance of the banded and rufous hare-wallabies, *Lagostrophus fasciatus* and *Lagorchestes hirsutus*. Biological Conservation **60**: 157-166.

Shortridge, G.R. (1909). Account of the geographical distribution of the marsupials and monotremes of south-west Australia, having special reference to the specimens collected during the Balston expedition of 1904-1907. Proceedings of the Zoological Society of London **LV**: 803-848.

Sinclair, A.J. (1988). Nutritional properties of kangaro meat. From: Kangaroo harvesting and the conservation of the arid and semi-arid lands. Ed(s). D. Lunney and G. Grigg. Proceedings of a Royal Zoological Society of New South Wales Conference. Australian Zoologist **24**:146-148.

Soderquist, T.S. (1995). The importance of hypothesis testing in reintroduction of the carnivorous marsupial *Phascogale tapoatafa*. From: Reintroduction biology of Australian and New Zealand Fauna. Ed. M. Serena, Surrey Beatty & Sons, Sydney.

Spencer, P.B.S. and Eldridge, M.D.B. (1998). A report on the taxonomic and population status of the Rufous hare-wallaby (*Lagorchestes hirsutus).* An unpublished report to the Mala Recovery Team .

Spencer, W.B. (1896). Zoology, From: Report on the work of the Horn Scientific Expedition to Central Australia, Ed. W.B. Spencer, Melville, Mullin and Slade, Melbourne.

Stanley-Price, M.R. (1989). Animal Reintroductions: The Arabian Oryx in Oman. Cambridge University Press, Cambridge.

Stanley-Price, M.R. (1991) A review of mammal reintroductions, and the role of the Reintroduction Specialist Group of IUCN/SSC. From: Beyond Captive Breeding: Reintroducing endangered mammals to the wild. Symposia Zoological Society of London No. 62. Ed. J.H.W. Gipps, Clarendon Press, Oxford, pp. 9-25.

Starfield, A.M. and Bleloch, A.L. (1988). Building models for conservation and wildlife management. MacMillan, New York.

Start, A.N., Burbidge, A.A., Sinclair, E. & Wayne, A. (1995). Lost and Found: Gilbert's Potoroo. Landscope **10**(3): 28-33.

Taylor, A.C., Sherwin, W.B. and Wayne, R.K. (1994). Genetic variation of microsatellite loci in a bottlenecked species : the Northern Hairy-nosed Wombat *Lasiorhinus krefftii* Molecular Ecology **3**: 277-290.

Thomas, M.O.W.G. (1987). The relationship between edaphic features and halophyte zonation in the Tanami Desert. Unpublished Bachelor of Natural Resources Thesis, University of New England, Armidale.

Troughton, E. (1965). Furred Animals of Australia. Angus and Robertson, Sydney.

Van de Graff, W.J.E., Crowe, R.W.H., Bunting, J.A. and Jackson, M.J. (1977). Relict early canozoic drainages in arid Western Australia. Zeitschrift fur Geomorphologie N.F. **21**: 379-400.

Vaughan, B.E. and Boling, E.A. (1961). Rapid assay procedure for tritium labelled water in body fluids. Journal of Laboratory and Clinical Medicine. 57: 159-164.

Wallis, I.R. and Green, B. (1992). Seasonal field energetics of the Rufous Rat-kangaroo (*Aeprymnus rufescens*). Australian Journal of Zoology **40**: 279-290.

Wallis, I.R. and Green, B. and Newgrain, K. (1997). Seasonal field energetics and water fluxes of the Long-nosed Potoroo (*Potorous tridactylus*) in southern Victoria. Australian Journal of Zoology **45**: 1-11.

White, G.C. and Garrot, R.A. (1990). Analysis of Wildlife Radio-Tracking Data. Academic Press, New York.

Wilson, A.C. and Stanley-Price, M.R. (1994). Reintroduction as a reason for captive breeding. From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner. Chapman and Hall, London.

Wilson, R.J., Drobney, R.D. and Hallet, D.L. (1992). Survival, dispersal and site fidelity of wild female Ring-necked pheasants following translocation. Journal of Wildlife Management 56(1): 79-85.

Winkworth, R.E., Perry, R.A. and Rossetti, C.O. (1962). A comparison of methods of estimating plant cover in an arid grassland community. Journal of Rangeland Management **15**: 194-196.

Wodzicki, K. and Flux, J.E.C. (1967). Guide to introduced wallabies in New Zealand. Tuatara **15**: 47-59.

Wolff, J.O. (1994) More on juvenile dispersal in mammals. Oikos **71**: 349-352.

Woodford, M.H. and Kock, R.A. (1990). Veterinary considerations in reintroduction and translocation projects. From: Beyond Captive Breeding: reintroducing endangered mammals to the wild. Zoological Society of London Symposia 62. Ed. J.H.W. Gipps, Oxford Science Publications, London.

Woodford, M.H. and Rossiter, P.B. (1994). Disease risks associated with wildlife translocation projects. From: From: Creative Conservation: Interactive management of wild and captive animals. Ed(s). P.J.S. Olney, G.M. Mace & A.T.C. Feistner. Chapman and Hall, London.

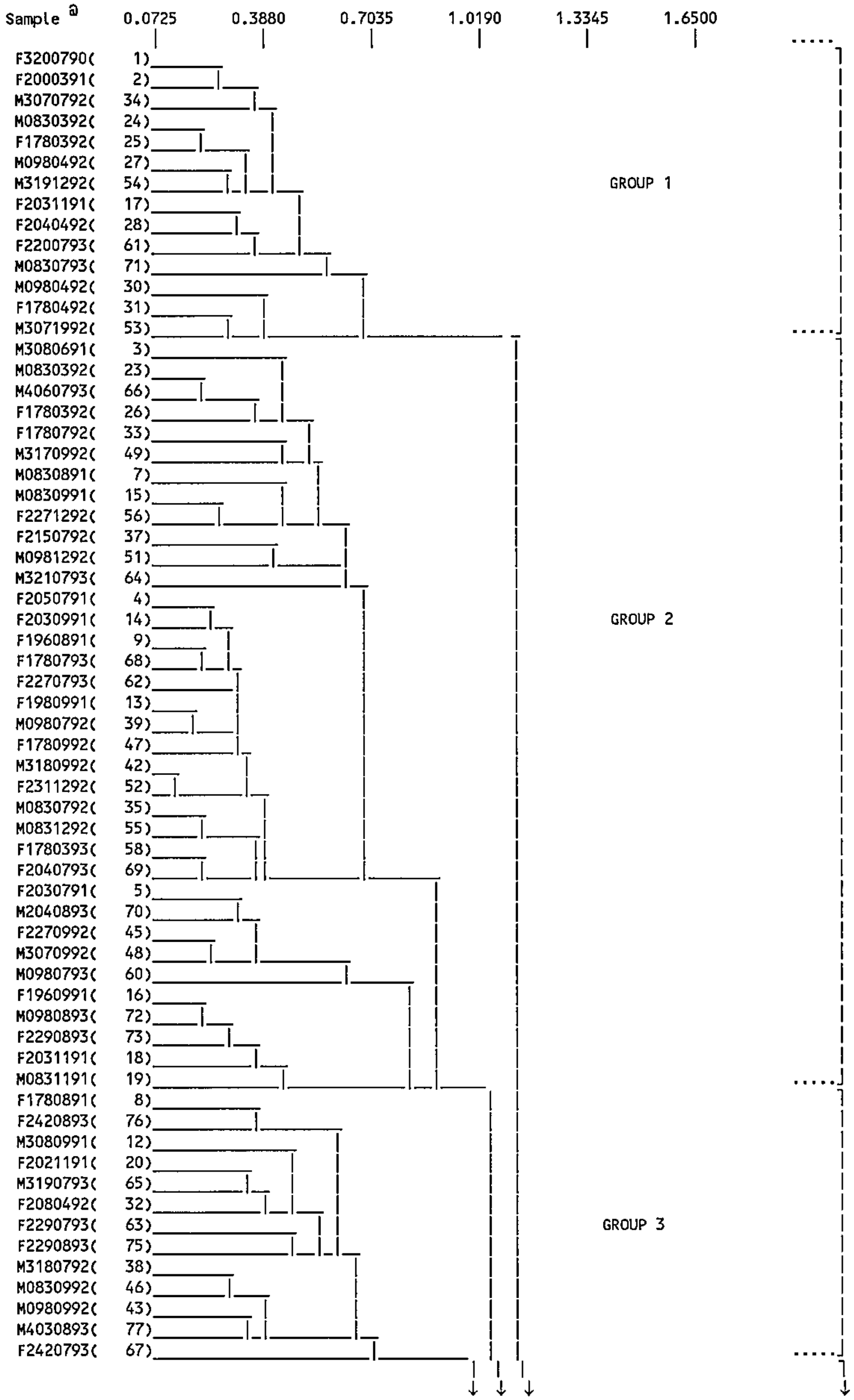
Zar, J.H. (1996). Biostatistical Analysis, 3rd Edition. Prentice Hall, New Jersey.

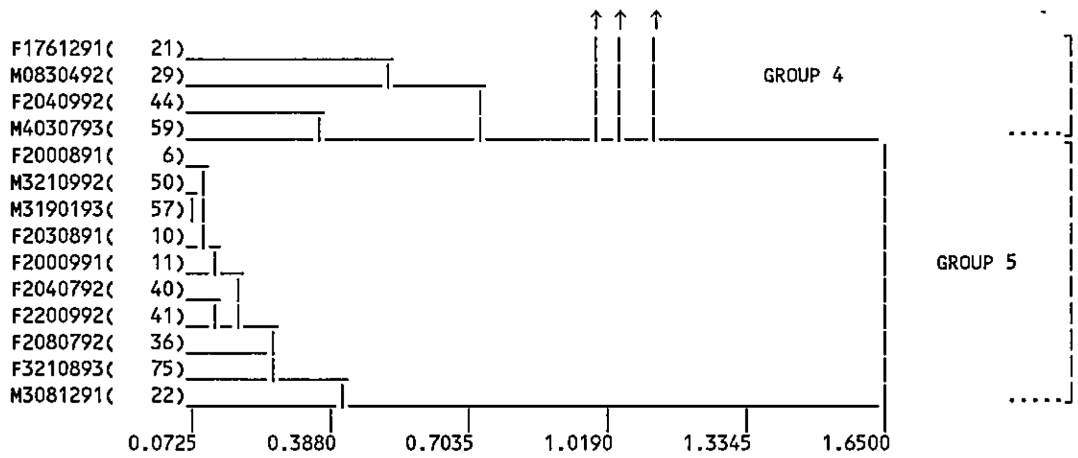
Appendix I has been removed as it was published as the following journal article:

McLean, I. G., Lundie-Jenkins, G., Jarman, P. J. (1996). Teaching an endangered mammal to recognise predators, *Biological Conservation*, 75,(1), 51-62.

https://doi.org/10.1016/0006-3207(95)00038-0

Appendix 2: Dendogram derived from Agglomerative Hierarchical Fusion of dietary analyses for known individual Mala at the Sangster's Bore release site.





@ Samples are identifed using the following unique 8 character nmemonic system.
(Sex = MorF, Animal ID = XXX, Month Collected = MM, Year Collected = YY)
∴ M0830992 = Male 083 collected September 1992

RECOVERY PLAN FOR THE MALA

(*Lagorchestes hirsutus*)

A report submitted to
Australian Nature Conservation Agency
Endangered Species Program (Project 188)

by

Geoff Lundie-Jenkins

Conservation Commission of the Northern Territory
Arid Zone Research Institute,
P.O. Box 1046, Alice Springs, N.T. 0871

for the Mala Recovery Team

Conservation Commission of the Northern Territory

1995

TABLE OF CONTENTS

			Page
SUMMARY			4
1.	INTRODUCTION		
	1.1	Description of species	5
	1.2	Distribution	5
	1.3	Habitat	6
	1.3.1	Habitat requirements and use	6
	1.3.2	Role of fire	7
	1.4	Life history/ecology	7
	1.4.1	Diet and feeding strategy	7
	1.4.2	Reproduction	7
	1.4.3	Vulnerability to poisoning programs	8
	1.5	Reasons for listing	8
	1.6	Existing conservation measures	8
	1.6.1	Reservation/listing	8
	1.6.2	Captive breeding	9
	1.6.3	Reintroduction	9
	1.7	Strategy for recovery	10
2.0	RECOVERY OBJECTIVE AND CRITERIA		10
3.0	RECOVERY ACTIONS		11
	3.1	Population and habitat monitoring	11
	3.1.1	Bernier and Dorre Islands	11
	3.1.2	Mainland reintroduced populations	11
	3.2	Habitat management	12
	3.2.1	Protection and management of island habitats	12
	23.2.2	Maintenance of fire mosaics near reintroduced populations	12
	3.2.3	Negotiation of Tanami conservation areas	12
	3.2.4	Research effects of burning regime	13
	3.3	Population genetics	13
	3.3.1	Clarification of sub-species status of 3 known populations	13
	3.3.2	Conservation genetics of captive and released populations	13
	3.4	Captive breeding program	14
	3.4.1	Maintenance and expansion of captive populations	14
	3.4.2	Research into oestrus detection and artificial insemination	14

3.5 Translocation to offshore island 14
3.5.1 Feasibility study of translocating mainland form to offshore island 15
3.5.2 Selection of suitable island 15
3.5.3 Translocation to offshore island 15
3.6 Translocations on mainland 15
3.6.1 Translocation to Heirisson Prong 15
3.6.2 Selection of additional release sites 16
3.6.3 Translocation to selected sites 16
3.7 Recovery Team administration 16

4.0 IMPLEMENTATION SCHEDULE 24

ACKNOWLEDGMENTS 27

BIBLIOGRAPHY 27

APPENDICES 30

I Details of Recovery Costings

FIGURES

1 The historic distribution of Mala as documented from museum specimens, sub-fossil deposits and aboriginal informants 4

SUMMARY

Current Species Status:

Endangered (ANZECC, 1991), Specially Protected (Regulations of the Territory Parks and Wildlife Conservation Act), Appendix 1 of CITES. Formerly distributed throughout spinifex deserts of central and western Australia. Mainland subspecies now presumed extinct in the wild and reduced to captive colonies and 2 experimental reintroduction programs. Bernier and Dorre Island subspecies (W.A.) apparently stable.

Habitat Requirements and Limiting Factors:

Formerly in low shrubland of eastern Wheatbelt (W.A.) but mainly in spinifex hummock grasslands of central deserts (N.T., W.A. and S.A.). Tanami colonies formerly associated with saline paleodrainage system, sanddunes and tight fire patterns. Large areas of spinifex desert appear suitable providing exotic predator (Feral Cats and Foxes) and Rabbits are at low densities or controlled and fire is properly managed.

Recovery Plan Objectives:

Secure and maintain existing natural populations and effect reintroduction of Mala into secure habitats.
Development of effective management and translocation prescriptions for the species.

Recovery Criteria:

(1) Two self-sustaining populations of mainland sub-species.
(2) Clear management prescriptions for island and mainland populations.
(3) Successful negotiation of conservation areas in the Tanami Desert.
(4) Clarification of the species genetics.

Actions Needed:

A recovery team comprising members from CCNT, CALM, ANPWS, CSIRO, Western Plains Zoo and other organisations, as appropriate, will be appointed to coordinate and supervise the following actions:
(1) Monitoring of wild and reintroduced Mala populations and habitat.
(2) Management of habitats in and adjacent to Mala populations.
(3) Clarify the population genetics of the 3 recognised sub-species of Mala.
(4) Captive breeding to provide animals for translocations.
(5) Translocation of mainland sub-species to offshore island.
(6) Translocation of Mala to secure mainland habitats.

Costs of Recovery: 1993 prices in $000's/year

Total cost (TC) and Endangered Species Program (ESP) funds required (TC - other), NB = Not budgetted in current plan

Action	(1)		(2)		(3)		(4)		(5)		(6)		(7)		Total	
	TC	ESP	TC	ESP	TC	ESP	TC	ESP	TC	ESP	TC	ESP	TC	ESP	TC	ESP
1993	66	40			18	10									84	50
1994	66	40													66	40
1995	66	40							4	-					70	40
1996	126	92	11	4			38	17	10	5			11	3	196	121
1997	92	70	11	4			38	17	64	44			11	3	216	138
1998	39	17	11	4			38	17	10	-			11	3	109	41
1999	68	39	11	4			21	-	-	-	NB	NB	11	3	111	46
2000	39	17	11	4			21	-	-	-			11	3	82	24
2001	39	17	11	4			21	-	-	-			11	3	82	24
Total	601	372	66	24	18	10	177	51	88	49	NB	NB	66	18	1016	524

Biodiversity Benefits:

Reintroduction, habitat management and exotic species control to benefit many C.W.R. species, 2 extant species and 9 mammals and 1 bird that could be reintroduced.

1. INTRODUCTION

1.1 Description of species

The Rufous Hare-wallaby or Mala, *Lagorchestes hirsutus* was described in 1844 from specimens procured by John Gilbert in the wheat belt country of Western Australia (Gould 1844). They are small rabbit sized wallabies standing approximately 300 mm high and weighing between 700 g and 2 kg. Their general fur colour, particularly on the hind quarters, chest and abdomen, is a rich sandy buff. The fur on the head and back has a greyish white tint and hair length increases towards the lower portion of the back, giving the animal a conspicuous "shaggy" appearance (Troughton 1965). The species name *hirsutus* refers to this characteristic. There is no apparent colour differentiation between the sexes, but females are on average larger than males of similar age.

Two distinct island sub-species of the Mala have also been recognised (Tate 1948, Troughton 1965). The Bernier Island sub-species, *L. hirsutus bernieri*, has shorter ears and its pelage is noticeably paler in colour, while the Dorre island form, *L. hirsutus dorreae*, is redder than the mainland form and its skull is narrower between the orbits (Troughton 1965). More recent investigations by Courtney (1993) support maintenance of the island subspecies and provide evidence for the possible subspeciation of the central Australian form. Consistent differences were identified between central Australian individuals and both the island forms and the *L. h. hirsutus* type specimen in pelage and cranial characters.

The Mala is distinguished from the other members of its genus on the basis of both external features and aspects of its dentition and skull morphology (Tate 1948). The Mala is the second smallest of the hare-wallabies, Finlayson (1943) having judged *L. hirsutus* to be considerably larger than *L. asomatus* on the basis of his measurements of the aged type skull for the latter. Like the other members of its group, the Mala is generally considered to be nocturnal and solitary.

1.2 Distribution

The Mala was once one of the most abundant and widespread macropods of central Australia. The accounts of early explorers bear testimony to this fact, and the extent of its former distribution is well reported by Aborigines (Burbidge *et al.* 1988). They recorded that *L. hirsutus* was once distributed throughout the great spinifex deserts and peripheral shrublands of Australia's central west.

The former distribution of *L. hirsutus* has previously been projected by a number of authors (Shortridge 1909, Newsome 1971, Burbidge and Johnson 1983; Fig. 1). These have generally shown that the species was distributed through the interior areas of Western Australia, northern South Australia and the central and southern regions of the Northern Territory. Some uncertainty, however, surrounds the exact limits of the species' former range, particularly its eastern and northern limits. Past location records for *L. hirsutus* come from Macdonald Downs north east of Alice Springs to Beverly in south-west W.A., and from Banka Banka in the north to Everard in South Australia. The absence of records from some areas within the presumed limits of the species may well be an artefact of inadequate sampling. It may also reflect the mode of occurrence of this species which was reported by Finlayson (1961), during his extensive surveys through central Australia between 1931 and 1956, as being:

> "fluctuating and discontinuous and with isolated colonies widely sundered",

a view also supported by Ride and Tyndale-Biscoe (1962). It could however also reflect a persistently discontinuous distribution.

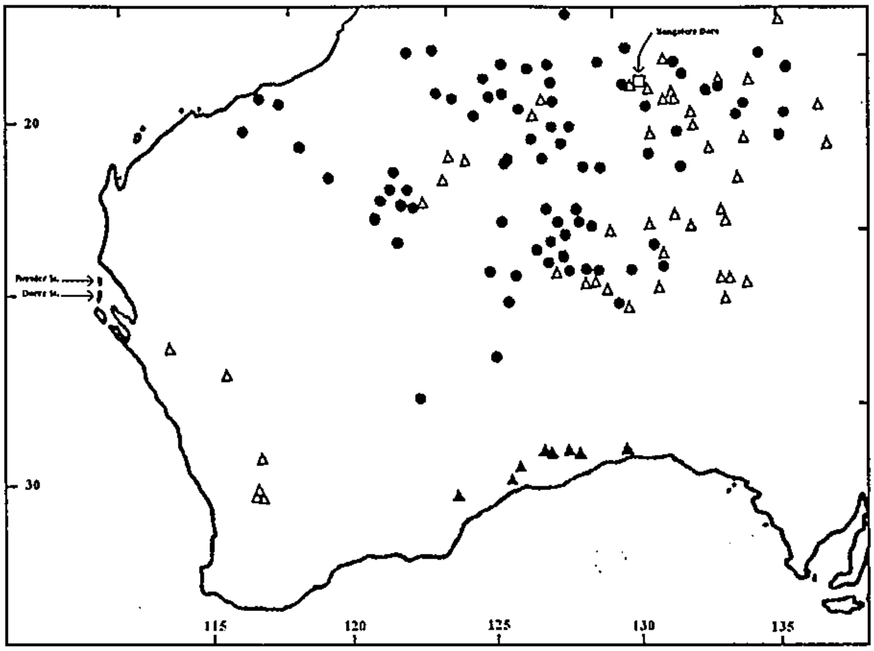


Figure 1 The historic distribution of Mala as documented from museum specimens, sub-fossil deposits and aboriginal informants.

Δ	Museum and historical records
●	Aboriginal accounts
▲	Subfossil material

Over the past fifty years the Mala has suffered a severe decline and at the present time it is considered one of the rarest and most limited species in its distribution. Extensive ground and aerial surveys through regions of the Northern Territory and Western Australia (Gibson 1986, Burbidge and Pearson 1988) have failed to locate additional populations. The last known "wild" mainland populations of Mala from a small region of the Tanami Desert, N.T. were driven to extinction by exotic predators and wildfire (Lundie-Jenkins *et al.* 1993b, Johnson & Lundie-Jenkins 1994). At present the species is known only from Bernier and Dorre Islands and from captive and reintroduced populations in the Northern Territory (Gibson *et al.* 1994).

1.3 Habitat

1.3.1 Habitat requirements and use

Mala on Bernier and Dorre Islands are found in heath or open steppe associations and in spinifex or porcupine grass (*Triodia*) areas (Ride and Tyndale-Biscoe 1962, Short & Turner 1991). By comparison recently extant colonies in the Tanami Desert occupied areas dominated by mature, but not senescent, spinifex *Triodia pungens* (Bolton and Latz 1978). Earlier accounts indicate that a range of other habitat types were also utilised by the species. Gilbert (in Gould 1863) described his original specimens as coming from low scrub country, while Finlayson (1963) gives an account of Aborigines hunting Mala through spinifex-mulga country with the use of fire. Unfortunately the greater part of our knowledge of the species' habitat preferences is derived from studies carried out in recent times, over their presently limited range.

Studies in the Tanami Desert showed that Mala in these regions were dependant upon a specialised form of spinifex habitat (Lundie-Jenkins 1989). Aspects of the habitat structure and diversity appear to be important in delineating between suitable and unsuitable areas. Patchiness, hummock size, food diversity and the degree of senescence, in particular, were identified as influential factors. The adjacency and accessibility of each of these factors to the Mala also appears to be crucial.

Mala in the Tanami Desert showed definite seasonal patterns of habitat use (Lundie-Jenkins 1993). The dispersal of hare-wallaby activity between and within two adjacent vegetation systems was found to vary in response to the availability and palatability of feed plants. The home ranges of individual hare-wallabies were found to consist of large areas within the dense spinifex habitat and small concentrated feeding areas within caliche habitat.

1.3.2 Role of fire

Fire generated succession is thought to be important in creating the combinations of habitat features favoured by the Mala. Areas of spinifex regenerating after fire provide important feeding areas for *L. hirsutus* (Bolton & Latz 1978, Lundie-Jenkins *et al.* 1993). The density of wallaby sign in one burnt area sampled by Lundie-Jenkins (1993) was found to be three times higher than that in an adjacent unburnt site. Regrowth in such areas is generally more succulent and nutritious than the mature vegetation. Observations of fire recovery in a number of non-spinifex plants indicate that some are intolerant to frequent fires. More mature spinifex stands, greater than 5 years since fire, is important in terms of daytime shelter. Fire appears to be of less importance on Bernier and Dorre islands where natural habitat diversity is higher (Short & Turner 1991).

1.4 Life history/ecology

The greater part of our knowledge of the life history traits for the Mala is derived from studies conducted on the recently extant mainland populations in the Tanami Desert (Bolton & Latz 1978, Lundie-Jenkins 1993). Only a limited amount of comparative data are available from studies of the island forms of Mala (Ride & Tyndale-Biscoe 1962).

1.4.1 Diet and feeding strategy

Mala were found to utilise a large range of food plants within their environment on a seasonal basis (Ride & Tyndale-Biscoe 1962, Pearson 1988, Lundie-Jenkins *et al.* 1993). In the Tanami Desert perennial grasses, principally *Eragrostis falcata* and *Eriachne obtusa*, were the most consistent "staple" food items. Monocot seeds were a favoured food item when available and sub-shrubs and shrubs acted as important secondary food plants. The Mala showed dramatic shifts between preferred species in relation to their availability and palatability. Insects appear to be an important source of dietary nitrogen when conditions are poor and productivity is low.

1.4.2 Reproduction

In captivity Mala were found to breed virtually continuously throughout the year (Lundie-Jenkins 1989). Reintroduced Mala at two sites in the Tanami also showed no seasonality of births but survival of pouch young appeared to be strongly influenced by rainfall and hence food quality. Age at sexual maturity for females ranged between 5 and 18 months and for males was approximately 14 months. Captive reared animals remained reproductive up to 8 years of age.

1.4.3 Vulnerability to poisoning programs

Trials conducted by King (unpublished) found Mala to have a high tolerance to the compound 1080. All animals tested survived doses up to 20 mg/kg. This is significantly higher than *Lagorchestes conspicillatus* which died a levels of around 5 mg/kg. On this basis Mala should be at almost no risk from accidental poisoning during any rabbit or fox control progammes.

1.5 Reasons for Listing

The Mala is one of five described species of hare-wallabies, a group of small to medium sized macropods (1-3kg) which were formerly widespread through inland regions of Australia. Over the past 50 years the distribution of all the hare-wallabies has declined severely. Of the five known species two are now extinct, two are rare except in very restricted habitats and only one, the Spectacled Hare-wallaby *Lagorchestes conspicillatus*, is reasonably common (Table 1).

Table 1
Status of the Hare-wallabies

Species	Qld	NSW	S.A.	W.A.	N.T.	Islands
Lagorchestes						
L. conspicillatus	D	-	-	D	D	Barrow Island
L. hirsutus	-	-	E	E	R	Bernier & Dorre
L. leporides	-	E	E	-	-	-
L. asomatus	-	-	-	E	E	-
Lagostrophus						
L. fasciatus	-	-	-	E	-	Bernier, Dorre & Barrow Islands

D= Range & numbers reduced; E=Extinct; R=Rare; -=Never Occurred.
(Modified from Burbidge 1977, Burbidge et al. 1988)

The mainland subspecies of the Mala is now only represented in 2 experimental reintroduction programmes and in captive colonies. Recent events have served to demonstrate the susceptibility of these populations to extinction due to introduced predators or wildfire. During the later part of 1987 one localised population of Mala was driven to extinction due to predation by a single fox (Lundie-Jenkins 1989). More recently, an extensive wildfire in the area of the remaining "wild" colony has severely reduced the amount of suitable habitat available to the Mala. Feral Cats have been a recurring problem in programmes to reintroduce captive bred Mala into the Tanami Desert (Gibson *et al.* 1994).

The Bernier and Dorre Island populations of Mala appear to be relatively stable (Short and Turner 1991). However, island populations are well known for their susceptibility to catastrophic events.

1.6 Existing conservation measures

1.6.1 Reservation / listing

The current status of the Mala on mainland Australia is at best precarious and on Bernier and Dorre Islands it is certainly vulnerable (Johnson 1988). Legal protection and recognition of the species' endangered status are afforded by way of its listing on the following International and Australian conventions:

- Endangered, Part 1 Schedule 1 of the Endangered Species Protection Act 1992.

- Appendix 1 of Convention on International Trade in Endangered Species (C.I.T.E.S.).

- International Union for Conservation of Nature and Natural Resources (I.U.C.N.) Red Data Book.

- ANZEC List of Endangered Fauna.

- Schedule IV: ANZEC *ad hoc* Working Group on Management of Endangered Vertebrates (Species with the highest priority for management action).

Direct protection of the species' island habitats is provided through land reservations with both Bernier and Dorre Islands classified as Class "A" faunal reserves, with strictly controlled access. By comparison the Tanami colonies occur on Aboriginal freehold land. However, negotiations are underway between the Conservation Commission of the Northern Territory and traditional owners via the Central Land Council for the establishment of conservation areas to protect the species. Programmes of fire management, predator control and experimental reintroduction have been carried out in the Tanami Desert in collaboration with Warlpiri Aborigines.

1.6.2 Captive breeding

A captive breeding colony of Mala was established in Alice Springs in 1980 using "wild" stock obtained from the Tanami Desert. The aim of establishing this colony was to breed the species successfully in captivity to supply animals for reintroduction into parts of their former range. Stock from this colony have also been used to establish additional captive colonies at Western Plains Zoo (Dubbo, N.S.W.), and the Monarto Zoological Park (Table 2).

Table 2
Captive Mala Colonies

Location		Composition	Total
Arid Zone Research Institute	Alice Springs	13:25:1	39
Western Plains Zoo	Dubbo	6:6:0	12
Monarto Zoological Park	Adelaide	2:2:0	1
TOTAL		22:31:1	54

1.6.3 Reintroduction

Two experiments in reintroducing the Mala have been initiated: one at the site of the colony that went extinct in 1987 and the other in the fresh-water paleodrainage line that traditional Aboriginal owners selected on the basis of habitat suitability and use by Mala in living memory. Both have suffered setbacks due to the impact of exotic predators, principally feral cats (Gibson *et al.* 1994, Lundie-Jenkins & Bellchambers 1994). Both programmes have also significantly increased our knowledge of the processes and logistics of reintroductions and provided insights into the factors effecting natural and reintroduced Mala populations. Whilst small Mala populations still persist at both sites neither could be considered a long term viable population.

1.7 Strategy for Recovery

This recovery plan will run for a term of 10 years from 1994 to 2004 inclusive. Five primary strategies will be pursued during this term and are presented below in order of proposed implementation. However, once commenced many of these strategies will be run concurrently.

(i) Monitoring of natural and reintroduced Mala populations and habitat at island and mainland sites. Monitoring will be ongoing and will be used to assess the well-being of populations and to determine management priorities.

(ii) Habitat management in and around natural and reintroduced Mala populations. Protection and enhancement of Mala habitat will be ongoing. Research into the effect of prescribed burning regimes will commence in 1996. Negotiation of conservation areas in the Tanami Desert will continue.

(iii) Research the conservation genetics of the Mala. Clarify the subspecific status of Mala from Bernier and Dorre Islands and the mainland gene pool through analysis of DNA. Investigate the genetics of captive population of the mainland form of Mala maintained at the AZRI and Western Plains Zoo.

(iv) Continuation of captive breeding at the AZRI and Western Plains. A captive breeding program has been operating since 1980 and will be ongoing to provide Mala for the translocation project.

(v) Translocation of captive bred Mala into areas of vacant suitable habitat at island and mainland sites. Options for introduction of captive Mala to an offshore island are being investigated with implementation scheduled for 1995. Future mainland translocation options include Lake MacKay Islands, Heirisson Prong, Peron Peninsula and new sites in the Tanami Desert

A recovery team comprising members from CCNT, CALM, ANPWS, CSIRO, Western Plains Zoo and other organisations, as appropriate, will be appointed to coordinate and supervise theses strategies. The recovery team will report annually to ANCA.

2.0 RECOVERY OBJECTIVE AND CRITERIA

The objectives of this recovery plan are to:

(1) Secure and maintain existing natural populations and effect reintroduction of Mala into secure habitats.
(2) Development of effective management and translocation prescriptions for the species.

The criteria for successfully achieving this objective will be

(1) Two self-sustaining populations of mainland sub-species.
(2) Clear management prescriptions for island and mainland populations.
(3) Successful negotiation of conservation areas in the Tanami Desert.
(4) Clarification of the species genetics.

It is unlikely that the Mala will be removed from the endangered list within the time frame of the recovery plan. Mala will still require indefinite protection after 10 years.

3.0 RECOVERY ACTIONS

Recovery actions for the Mala are presented below. Costings have been calculated at 1994 prices. Unless otherwise stated contributions by participating state agencies include salaries for research and technical staff. Actions undertaken as normal operations by state agency staff have not been costed. Details of costings are presented as Appendix 1 of this document.

1.0 Population and Habitat Monitoring

Regular monitoring of wild and reintroduced Mala populations and their habitats is an essential component of the recovery strategies. Monitoring would include quantitative assessment of the status of all Mala populations and qualative assessment of important habitat parameters including vegetation structure and floristics, feral animal populations and fire history.

Monitoring would be undertaken by the responsible state/federal agencies following a protocol developed and ratified by the Mala Recovery team.

1.1 Monitoring of Bernier and Dorre Islands

Monitoring of the Bernier and Dorre island Mala populations should be undertaken at least every 3 years following the procedures utilised by Short and Turner 1992. This will provide quantitative data on the abundance and distribution of Mala on the 2 islands. The establishment of habitat monitoring sites should also be undertaken in conjunction with these surveys. Initial monitoring would be undertaken by CSIRO on a full cost recovery basis utilising ESP funds with CALM commiting increased support in subsequent years as other projects are finalised.

CSIRO Contribution:	$ 7 000
ESP Funds Required:	$22 512
Total Cost of Action:	$29 512

1.2 Monitoring of mainland re-introduced populations

Monitoring of the mainland reintroduced populations is critical given that many of the factors which contributed to the extinction of this form in the wild are still active. Monitoring of these populations would combine spotlight transects, similar to those conducted for the island populations, and live trapping. Habitat attributes to be monitored would include predator activity by sand tracking techniques, vegetation cover and condition by wheelpointing and permanent photo-points. Monitoring would be conducted by the CCNT which would contribute vehicles and running expenses, field equipment and technical support. ESP funds are required to support the employment of a Research scientist and 0.5 of a technical position to coordinate the monitoring and management of these projects. The research position would extend only until 1998.

CCNT Contribution:	$26 800
ESP Funds Required:	$70 200
Total Cost of Action:	**$97 000**

2.0 Habitat Management

The maintenance of habitats suitable for the persistance and growth of Mala populations under a range environmental conditions is an important part of the recovery process. Ideally management should be planned so as to lead to a minimal management situation whereby populations can continue to persist with a minimum of intervention by managers. Management activities which may be required in the interests of Mala conservation include exotic species removal/control, fire management/control and food and water supplementation.

2.1 Protection and management of island habitats.

At present their are few management activities undertaken on either Bernier and Dorre Islands and such activities are strictly controlled under the listing of the islands as Class A Fauna Reserves. It is important however that contingency plans be put in place in the event of catastrophes such as exotic species introductions or wildfire. Such plans should be developed by CALM in consultation with the Mala Recovery team and will be incorporated in the Shark Bay World Heritage Area management plan (Reference).

2.2 Maintenance of fire mosaics near reintroduced populations

Establishment and maintenance of a mosaic of different post-fire recovery states of spinifex habitats affords the mala populations with protection from the effects of large wildfires and provides a range of alternative feeding and sheltering habitats for the species. These operations would be conducted by the CCNT in cooperation with the CLC and Aboriginal traditional owners. CCNT would contribute vehicles and running costs and field equipment. ESP funds are required for the employment of Aboriginal consultants to assist in the annual burning programme and for the purchase of Landsat imagery of the 2 sites. The project would be overseen and coordinated by the ESP funded professional officer (1.1.2).

CCNT Contribution:	$ 6 900
ESP Contribution:	$ 4 000
Total Cost of Action:	**$10 900**

2.3 Negotiation of conservation areas in the Tanami Desert with Aboriginal traditional owners.

There is a need for consultation with Central Land Council and traditional owners leading to negotiation of an agreement for joint management of the Tanami region. This will provide security of management over the re-introduced populations of Mala. The presence of Mulgara and Bilby provides economies of scale in species/community management in this area of relatively undisturbed desert. Costs within normal CCNT operations.

2.4 Research effects of burning regime on movement patterns and subsequent survival and dispersal of Mala

Fire is an inevitable part of the desert landscape and management will need to provide the conditions for Mala to survive fire. Research would involve radio tracking of Mala before, during and in the 6 months following the deliberate destruction of their home range by fire. This would lead to determination of age related mortality patterns and investigation of movement patterns relative to detailed mapping of vegetation communities and fire. CCNT would contribute vehicle and running expenses, radio-telemetry equipment, field equipment and GIS mapping support. The ESP funded Professional Officer would coordinate the project (1.2) in conjunction with routine monitoring and management of the reintroduced populations. Implementation is contingent apon the outcomes of other actions therefore no costings have been completed.

3.0 Population Genetics

Resolution of the taxonomy of the Mala is needed to clarify endangered species status and to determine options for translocations and formation of hybrid populations. Screening of captive population will assist management to minimise inbreeding; screening of re-introduced populations will measure changes in inbreeding levels and need for provision of additional males.

3.1 Clarification of subspecific status through DNA analysis of bloods from the Bernier, Dorre and Tanami populations

Blood samples collected from island and mainland populations of Mala will be subjected to standard DNA analysis techniques to investigate the extent of genetic differences within and between the currently recognised sub-species.

3.2 DNA fingerprinting of captive and released populations

Blood samples from founder and captive reared Mala within the captive population and the reintroduced populations will be subjected to standard DNA and electrophoretic analyses to investigate the degree of genetic diversity present within the population and to evaluate the effect of current breeding practices on genetic diversity at the molecular level. For both actions CCNT would contribute vehicles and running costs and field equipment. ESP funds are required to cover the DNA analyses and travel costs. The project would be overseen and coordinated by the ESP funded Professional Officer (1.2).

Costs for 3.1 and 3.2 combined

CCNT Contribution :	$ 8 260
ESP Contribution :	$10 000
Total Cost of Action	**$18 260**

4.0 Captive Breeding Programme

The principal aims of the captive breeding programme for the Mala are to secure and maintain representatives of the mainland gene pool in captivity; provide Mala for re-introduction programmes and public education and relations.

4.1 Maintenance and expansion of captive populations

Captive populations would be coordinated by the Australasian Species Management Plan for Zoo Populations of the Mala to be jointly prepared by CCNT, WPZ, MZP and other institutions with interests in maintaining populations of Mala in captivity. This document would be ratified by the Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA) and the Mala Recovery Team. Routine activities include feeding and veterinary care; maintenance of yard facilities; maintenance of SPARKS studbook; routine capture, marking and redistribution of breeding pairs within and between institutions. ESP funding is required to support 0.5 of a technical officer to maintain the CCNT population and the National computer studbook. Negotiations would be conducted to effect transfer of the studbook and population management functions to zoo personnel sometime in 1999.

CCNT Contribution :	$11 070
WPZ Contribution :	$ 5 505
MZP Contribution :	$ 5 505
ESP Contribution :	$16 800
Total Cost of Action	**$38 880**

4.2 Research into Oestrus detection and artificial insemination

As the captive Mala population is derived from a low number of wild founders it is important to ensure that ,as far as possible, the genes of all founders are equally represented within the population. Accurate detection of oestrus and artificial insemination techniques would enhanced our ability to manage the breeding population and equalise founder representation. Research would be undertaken by the University of Queensland in conjunction with WPZ. Funding for the project has been provided by the Australian Gas Company. Budgets will not be prepared until details of the projects scope are finalised.

5.0 Translocation to offshore island

Attempts to reestablish self-sustaining populations of Mala on the mainland have been severely hampered, principally by introduced predators. Island translocations appear to have a significantly higher probability of success and offer an opportunity to establish a new self-sustaining population. Whilst reestablishment of Mala on the mainland is the long term goal an island translocation would provide security for the species short term conservation.

5.1 Feasibility Study of translocation of mainland form to offshore island

A discussion paper addressing the issues related to translocation of mainland Mala to an offshore island will be prepared and circulated for review. This paper will cover logistics, genetics, island habitats, potential disturbance, costs, alternative strategies, behaviourial effects.

CCNT Contribution :	$ 2 150
CALM Contribution :	$ 2 150
ESP Contribution :	$ NIL
Total Cost of Action :	$ 4 300

5.2 Selection of suitable offshore island

Potential island sites both within and outside the former range of the Mala have been identified from data-base records (Burbidge unpublished). A detailed review of existing information on these sites would be compiled to identify a short list of suitable islands. Final selection of a site would be based on visits to the islands combined with an analysis of costs and logistics. A translocation proposal (TP) would be prepared following the ESAC Policy for Translocations for review by at least two experienced scientists. Officers from CCNT and CALM would be involved in the process and ESP funds would be required to cover the travel component of the study.

CCNT Contribution :	$ 680
CALM Contribution :	$ 3 900
ESP Contribution :	$ 5 330
Total Cost of Action :	$ 9 910

5.3 Translocation to offshore island

This action is dependant on the outcomes of Actions 3.5.1 & 3.5.2. The mode of operation and the involvement of various parties will be determined by the island site selected. Costing of this action will be made in consultation with the Recovery Team and state/territory agencies once a site is selected. An approximate budget is provided in Appendix 1 as a guide only since no decision has been made with regards to a suitable island site.

6.0 Translocations on mainland

Reestablishment of secure selfsustaining populations of Mala on the mainland is one of the major goals of the recovery plan for this species. Numerous options for translocation have been preposed and each shall be subject to a detailed Translocation Proposal (TP) following the ESAC Policy for Translocations.

6.1 Translocation to Heirsson Prong / Peron Peninsula

Any decision on the translocation of Mala to either of these restored sites will draw heavily on the the results of existing control and introduction programs. This includes the current CSIRO/Useless Loop Community program to reestablish the Burrowing Bettong on Heirsson Prong and the Project Eden initiative planned by CALM for the Peron Penisula. Mala are currently listed by CALM as one species for release into the Peron Peninsula area as part of its large commitment to the Project Eden habitat restoration project. Costings and agency involvement would be determined by the recovery team in consultation with the participating agencies.

6.2 Selection of additional release sites

Additional mainland sites also have potential for translocation of Mala provided effective management regimes can be designed to minimise the impacts of predators, introduced herbivores and wildlfire. These sites include Lake McKay Islands (N.T.), Great Sandy and Little Sandy Deserts (W.A.), and other areas of the Tanami Desert (N.T.). The suitability of some sites will be influenced by developments in feral animal control.

6.3 Translocation

This action is dependant on the outcomes of Actions 3.6.1 & 3.6.2. The mode of operation and the involvement of various parties will be determined by the island site selected. Costing of this action will be made in consultation with the Recovery Team and state/territory agencies once a site is selected. An indicative budget is provided in Appendix 1 but will be modified according to the island site selected.

7.0 Recovery Team Administration

The Mala recovery team shall contain representatives from each of the states/territories in which the species formerly occurred. In addition members with particular expertise shall be drawn from other areas. In this way the membership of the recovery team shall be widely spread over the Australian continent and opportunities for meetings will be constrained by travel costs. ESP funds would be required to enable core members of the recovery team to meet on at least an annual basis to review the progress of the recovery plan. Venues would be chosen to minimise travel expenses and non-core members would be required to meet their own costs for attendance.

CCNT Contribution :	$ 3 655
CALM Contribution :	$ 3 655
ESP Contribution :	$ 2 920
Total Cost of Action :	**$10 230**

4.0 IMPLEMENTATION SCHEDULE

IMPLEMENTATION SCHEDULE: MALA RECOVERY PLAN

Task #	Task Description	Priority	Feasibility	Responsible Party	Cost Estimate ($000's/year) 1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL
1.	Population and Habitat Monitoring													
1.1	Bernier and Dorre Islands	1	100%	a				22			22			44
				f				7			7			14
				a	40	40	40	70	70	17	17	17	17	328
1.2	Mainland reintroduced populations	1	100%	b	26	26	26	27	22	22	22	22	22	215
2.	Habitat Management													
2.1	Protection and management of island habitats	1	100%	c				N. op.	N. op.	N. op.	N. op.	N. op.	N. op.	N. op.
2.2	Maintenance of fire mosaics near reintroduced populations	1	100%	a				4	4	4	4	4	4	24
				b				7	7	7	7	7	7	42
2.3	Negotiation of Tanami conservation areas	1	100%	b				N. op.	N. op.	N. op.	N. op.	N. op.	N. op.	N. op.
2.3	Research effects of burning regime	2	100%	b				N.B.	N.B.	N.B.	N.B.	N.B.	N.B.	N.B.
3.	Population Genetics													
3.1	Clarification of sub-species status of 3 known sub-populations	1	100%	a	10									
				b	8									
3.2	Conservation genetics of wild and captive populations	2	100%	b	Costs in 3.1									
4.	Captive Breeding Programme													
4.1	Maintenance and expansion of captive populations	1	100%	a				17	17	17	-	-	-	51
				b				11	11	11	11	11	11	66
				e				5	5	5	5	5	5	30
				d				5	5	5	5	5	5	30
4.2	Research into oestrus detection and artificial insemination	2	100%	b				N.B.	N.B.	N.B.	N.B.	N.B.	N.B.	N.B.
				d										

Task #	Task Description	Priority	Feasibility	Responsible Party	Cost Estimate ($000's/year)									
					1993	1994	1995	1996	1997	1998	1999	2000	2001	TOTAL
5.	<u>Translocation to Offshore Island</u>													
5.1	Feasibility study of translocation of	1	100%	b			2							2
	mainland form to offshore island			c			2							2
5.2	Selection of suitable offshore island	1	100%	a				5						5
				b				1						1
5.3	Translocation to offshore island			c				4						4
		1	90%	a					44					44
				b					10					10
				c					10	10				20
6.	<u>Translocations on Mainland</u>													
6.1	Translocation to Heirsson Prong	1	95%	a						N.B.	N.B.	N.B.	N.B.	N.B.
				c										
6.2	Selection of additional release sites	1	100%											
6.3	Translocation	1	90%											
7.	<u>Recovery Team Administration</u>	1	100%	a				3	3	3	3	3	3	18
				b				4	4	4	4	4	4	24
				c				4	4	4	4	4	4	24
	Actions funded under original recovery plan	1	100%	a										
				b										
				a	50	40	40	121	138	41	46	24	24	524
	Total annual cost of Mala recovery			b	34	26	28	50	54	44	44	44	44	368
				c			2	8	14	14	4	4	4	50
				d				5	5	5	5	5	5	30
				e				5	5	5	5	5	5	30
				f				7			7			14
				TOTAL	84	66	70	196	216	109	111	82	82	1016

a: ESP Funds required
b: CCNT contribution
c: CALM contribution
d: Western Plains Zoo contribution
e: Monarto Zoological Park
f: CSIRO Wildlife & Ecology
N. op. = Normal operational costs
N.B. = No budget prepared

ACKNOWLEDGMENTS

Much of our current knowledge base on the Mala owes its origin to the generosity of funding bodies including World Wide Fund For Nature, The National Estate Grants-in-Aid Programme and the Endangered Species Programme. The author gratefully acknowledges the support provided by these groups in our efforts to conserve the Mala.

Appreciation is also extended to the Warlpiri Aboriginal people from the Yuendumu and Willowra communities, who have contributed valuable information and manpower to the Mala programme over a number of years.

Thanks also to co-workers at the Arid Zone Research Institute, particularly Ken Johnson, Lynn Day, David Gibson, Don Langford, Keith Bellchambers and Richard Southgate for their comments, criticisms and thought provoking discussions during the revision of this Recovery Plan

BIBLIOGRAPHY

Bolton, B.L. and Latz, P.K. (1978) The Western Hare-Wallaby Lagorchestes hirsutus (Gould) (Macropodidae), in the Tanami Desert. Australian Wildlife Research 5, 285-293.

Burbidge, A.A. (1977) The Status of Kangaroos and Wallabies in Australia. Report of the working group on macropod habitat of the standing committee of the Council of Nature Conservation Ministers. Australian Government, Canberra.

Burbidge, A.A. and Johnson, K.A. (1983) Rufous Hare-Wallaby. From. The Australian Museum Complete Book of Australian Mammals. Ed. Strahan, R., Angus and Robertson, Sydney.

Burbidge, A.A., Johnson, K.A., Fuller, P.F. and Southgate, R.I. (1988) Aboriginal knowledge of the mammals of the central deserts of Australia. Australian Wildlife Research 15, 9-39.

Burbidge, A.A. and Pearson, D.J. (1988) A search for the Rufous Hare-wallaby and other rare mammals in the Great Sandy and Little Sandy Deserts, Western Australia. Wildlife Research Bulletin (in press) Department of Conservation and Land Management, Perth.

Cole, J.R. and Gibson, D.F. (1987) Report on the Mala Re-introduction Programme in the Tanami Desert. Unpublished report to the Conservation Commission of the Northern Territory.

Courtney, J. (1993) The systematics of the Rufous hare-wallaby *Lagorchestes hirsutus* Gould 1844. International Theriological Society Congress, University of New South Wales, Sydney. pp 286.

Finlayson, H.H. (1943) A new species of Lagorchestes. (Marsupialia) Records of the South Australian Museum., 67, 319-321.

Finlayson, H.H. (1961) On central Australian mammals. Part IV. The distribution and status of central Australian species. Records of the South Australian Museum., 14, 141-191.

Finlayson, H.H. (1963) The Red Centre. Angus and Robertson Ltd., Sydney.

Frazer, A.J. (1962) The results of an expedition to Bernier and Dorre Islands, Shark Bay, Western Australia in July 1959. Fauna Bulletin No. 2, Fisheries Department of Western Australia.

Gibson, D.F. (1986) A biological survey of the Tanami Desert in the Northern Territory. Conservation Commission of the Northern Territory Technical Report No. 30.

Gibson, D.F., (1994) The rufous hare-wallaby: a history of experimental reintroduction of the Mala in the Tanami Desert. Proceedings of Conference on Reintroduction Biology of Australasian Fauna, Healesville, Victoria.

Gould, J. (1844) Descriptions of three new species of Halmaturus and Lagorchestes. Proceedings of the Zoological Society of London. XII, 31-32.

Gould, J. (1863) The Mammals of Australia. Vol. II. Taylor and Francis, London.

Johnson, K.A., Burbidge, A.A. and McKenzie, N.L. (1988) Australian macropods: status, causes of decline and future research and management. From: Kangaroos, Wallabies and Rat-Kangaroos. Eds. Grigg, G., Hume, I.D. and Jarman, P.J., Surrey Beatty and Sons, Sydney.

Johnson, K.A. (1988) Rare and Endangered: Rufous Hare-wallaby. Australian Natural History. 22, 406-407.

Loorham, C. (1985) The Warlpiri and the Rufous Hare-Wallaby. Habitat. 13, 8-9.

Lundie-Jenkins, G. (1993). Ecology of the rufous hare-wallaby, *Lagorchestes hirsutus* Gould (Marsupialia : Macropodidae) in the Tanami Desert, N.T.. I. Patterns of habitat use. Wildlife Research **20**, 457-76.

Lundie-Jenkins, G., Phillips, C.M. and Jarman, P.J. (1993). Ecology of the rufous hare -wallaby, *Lagorchestes hirsutus* Gould (Marsupialia : Macropodidae) in the Tanami Desert, N.T.. II. Diet and feeding strategy. Wildlife Research **20**, 477-94.

Lundie-Jenkins, G., Corbett, L.K. and Phillips, C.M. (1993). Ecology of the rufous hare -wallaby, *Lagorchestes hirsutus* Gould (Marsupialia : Macropodidae) in the Tanami Desert, N.T.. III. Interactions with introduced Mammal Species. Wildlife Research **20**, 495-511.

Newsome, A.E. (1971) Competition between wildlife and domestic livestock. Australian Veterinary Journal. 47, 577-586.

Pearson, D.J. (1988) The diet of the Rufous Hare-wallaby (Marsupialia: Macropodidae) in the Tanami Desert. Australian Wildlife Research. 16, 527-537

Ride, W.D.L. and Tyndale-Biscoe, C.H. (1962) Mammals From: The Results of an Expedition to Bernier and Dorre Islands, Shark Bay, Western Australia in July 1959. Ed. Frazer, A.J., Fauna Bulletin No. 2, Western Australian Fisheries Department.

Robinson, A.C., Robinson, J.F., Watts, C.H.S. and Baverstock, P.R. (1976) The Shark Bay Mouse, Pseudomys praeconis and other mammals on Bernier Island, Western Australia. The Western Australian Naturalist. 13, 149-155.

Saxon, E.C. (1983) Mapping the habitat of rare animals in the Tanami Wildlife Sanctuary (Central Australia) : An application of satellite imagery. Biological Conservation. 27, 243-257.

Short, J. and Turner, B. (1992) The distribution and abundance of the Banded and Rufous Hare -wallabies. Biological Conservation 60, 157-166.

Short, J., Bradshaw, S.D., Prince, R.I.T. & Wilson, G.R. (1992) Reintroduction of macropods (Marsupialia: Macropodidae) in Australia - A review. Biological Conservation 62, 189-204.

Shortridge, G.R. (1909) Account of the geographical distribution of the marsupials and monotremes of south-west Australia, having special reference tp specimens collected during the Balston expedition of 1904-1907. Proceedings of the Zoological Society of London. LV, 803-848.

Strahan, R. (1983) The Australian Museum Complete Book of Australian Mammals. Angus and Robertson, Sydney.

Tate, G.H.H. (1948) Results of the Archibold expedition, studies on the anatomy and phylogeny of the macropodidae. Bulletin of the American Museum of Natural History. 91, Part II.

Troughton, E. (1965) Furred Animals of Australia. Angus and Robertson, Sydney.

APPENDIX 1
DETAILS OF RECOVERY COSTINGS

CONTENTS

1 Population and habitat monitoring		23
1.1	Bernier and Dorre Islands	23
1.2	Mainland reintroduced populations	23
2 Habitat management		24
2.1	Protection and management of island habitats	24
2.2	Maintenance of fire mosaics near reintroduced populations	24
2.3	Negotiation of Tanami conservation areas	25
2.4	Research effects of burning regime	25
3 Population genetics		25
3.1	Clarification of sub-species status of 3 known populations	25
3.2	Conservation genetics of captive and released populations	25
4 Captive breeding program		26
4.1	Maintenance and expansion of captive populations	26
4.2	Research into oestrus detection and artificial insemination	27
5 Translocation to offshore island		27
5.1	Feasibility study of translocating mainland form to offshore island	27
5.2	Selection of suitable island	28
5.3	Translocation to offshore island	28
6 Translocations on mainland		29
6.1	Translocation to Heirisson Prong	29
6.2	Selection of additional release sites	29
6.3	Translocation to selected sites	29
7 Recovery Team administration		30

1. POPULATION AND HABITAT MONITORING

1.1 Monitoring of Bernier and Dorre Islands

(a) Description

52 days (2 x 26) days every 3 years are required for spotlight surveys of Bernier and Dorre islands by a RS and TO. Initial monitoring would be undertaken by CSIRO on a full cost recovery basis utilising ESP funds with CALM commiting increased support in subsequent years as other projects are finalised. ESP funds also required for transfer of personnel and equipment between the mainland and the islands using the Fisheries Department launch based at Carnarvon.

(b) CSIRO Contributions

Salaries: RS @ $250/day x 28	$ 7 000
Total	**$ 7 000**

(c) ESP Funds Required

CSIRO	
Salaries: RS @ $450/day x 5	$ 2 500
TO @ $250/day x 26	$ 7 280
TO Field Overtime	$ 4 760
Field Allowance: @ $36/night x 52	$ 1 872
Vehicle running costs: 3 800 km @ 25c/km	$ 1 900
Diesel fuel for Fisheries vessel	$ 1 500
Food: @ $8/day x 24 x 6	$ 1 140
Accomodation: @ $80/night x 2	$ 320
Consumables (batteries, generator fuel etc..)	$ 1 000
Volunteer insurance: @ $30/volunteer x 8	$ 240
Total	**$22 512**

(d) Total Cost of Action	CSIRO	$ 7 000
	ESP Funds	$22 512
	Total	**$29 512**

1.2 Monitoring of mainland re-introduced populations

(a) Description

Research Scientist (RS) and 0.5 x Technical Officer (TO) required to coordinate and undertake regular monitoring of re-introduced populations in the Tanami Desert. Research Scientist also responsible for coordination of recovery team and other recovery actions as indicated. RS employment extended until 1998 only.

(b) CCNT Contributions

Salaries: 0.125 x RS	$ 5 000
Aboriginal Consultants: (2x4x6) @ $100/day	$ 4 800
Vehicle Lease: @ $670/month	$ 8 000
Trailer Lease: @ $25/month	$ 300
Vehicle running costs: 12 000km @ 25c/km	$ 3 000
Bromilow Traps: 20 traps @ $250 each *	$ 5 000
Animal Food Supplements:	$ 500
Consumables (batteries, fuel etc..)	$ 200
Total	**$26 800**

* 1st year purchase cost only

(c) ESP Funds Required

CCNT	
Salaries: Research Scientist	$40 000
0.5 x Technical Officer	$14 000
Administration on-costs @ 20%	$10 800
Field Allowance: @ $36/night x 150	$ 5 400
Total	**$70 200**

* Budget reduced by RS salary plus on-cost and 75 days field allowance in 1998.

(d) Total Cost of Action	CCNT	$26 800
	ESP Funds	$70 200
	Total	**$97 000**

2. HABITAT MANAGEMENT

2.1 Protection and management of island habitats

(a) Description

Management of Bernier and Dorre Island habitats is coordinated under the Shark Bay World Heritage Area management plan. Costs within normal CALM and ANCA operations.

2.2 Maintenance of fire mosaics near reintroduced populations

(a) Description

Involves annual purchase and processing of LANDSAT satelite imagery to update fire history maps and application of controlled burns at the 2 Tanami reintroduced populations from 1995 to 2004. Processing requires 20 (2 x 10) days whilst burning operations would require 30 days (3 x 10 days) and would require employment of Aboriginal consultants to assist with on ground activities. Action coordinated and burning implemented by RS funded in Action 1.2.

(b) CCNT Contributions

Salaries: RS @ $250/day x 10	$ 2 500
TO @ $140/day x 10	$ 1 400
Computer Equipment lease:	$ 1 000
Aboriginal Consultants: (2 x 10) @ $100/day	$ 2 000
Total	**$ 6 900**

(c) ESP Funds Required

CCNT	
Salaries: RS	Action 1.2
Satelite Imagery:	$ 4 000
Total	**$ 4 000**

(d) Total Cost of Action	CCNT	$ 6 900
	ESP Funds	$ 4 000
	Total	**$10 900**

2.3 Negotiation of conservation areas in the Tanami Desert with Aboriginal traditional owners.

(a) Description

Involves liaison between the Conservation Commission of the Northern Territory, the central land Council and traditional Aboriginal owners. Costs within normal CCNT operations.

2.4 Research effects of burning regime on movement patterns and subsequent survival and dispersal of Mala.

(a) Description

Implementation contingent on outcomes of other actions therefore no costings have been completed.

3. POPULATION GENETICS

3.1 Clarification of subspecific status through DNA analysis of bloods from the Bernier, Dorre and Tanami populations, and

3.2 DNA fingerprinting of captive and released populations

(a) Description

Involves collection and analysis of blood samples from Bernier and Dorre Island and mainland captive and reintroduced Mala populations. Extraction and analysis of DNA conducted under contract by Curtin University. Action coordinated and collection of samples actioned by RS funded in Action 1.2.

(b) CCNT/CURTIN Contributions

Curtin	
Salaries : RS @ $250/day x 14	$ 3 500
TO @ $140/day x 14	$ 1 960
Laboratory Consumables: (Glassware, reagents etc.)	$ 200
CCNT	
Vehicle Costs: 2 400km @ 25c/km	$ 600
Data Analysis & reporting	$ 2 000
Total	**$ 8 260**

(c) ESP Funds Required

CCNT	
Salaries: RS	Action 1.2
Contract Analysis Fees: 100 samples @ $50/sample	$ 5 000
Travel Costs: (Airfares, Boat fuel etc..)	$ 3 000
Travel Allowances: 32 days @ $64/day	$ 2 000
Total	**$10 000**

(d) Total Cost of Action	CCNT/Curtin	$ 8 260
	ESP Funds	$10 000
	Total	**$18 260**

4. CAPTIVE BREEDING PROGRAM

4.1 Maintenance and expansion of captive populations

(a) Description

Captive populations maintained at 3 institutions Arid Zone Research Institute (CCNT), Western Plains Zoo (WPZ) and Monarto Zoological Park (MZP). Husbandry of CCNT population carried out by contractor whilst zoo populations require input by 1 keeper to care for up to 12 animals. Maintenance of the Mala studbook using the SPARKS program is the responsibility of the CCNT as they maintain the largest captive Mala population. Feed and veterinary expences are additional for each institution. Studbook and population management responsibilities to be transferred to zoo personnel in 1999.

(b) CCNT, WPZ & MZP Contributions

CCNT	
Contract for population husbandry:	$10 000
Food: 50 animals @ ^$10/week	$ 520
Veterinary Services: 1 hr/month (40,000/year FTE)	$ 300
SPARKS annual Fees:	$ 250
WPZ & MZP	

Salaries: 1 keeper, 1hr/day ($35 000/year FTE) x 2	$ 8 750
Food: 12 animals @ ^$2.50/week x 2	$ 260
Veterinary Services: 1 hr/week (40,000/year FTE)	$ 2 000
Total	**$22 080**

(c) ESP Funds Required

CCNT	
Salary: 0.5 x TO *	$14 000
Administration on-cost @ 20%	$ 2 800
Total	**$16 800**

* Funded until 1999 when responsibilities transferred to zoo personnel

(d) Total Cost of Action	CCNT & zoos	$22 080
	ESP Funds	$16 800
	Total	**$38 880**

4.2 Research into Oestrus detection and artificial insemination

(a) Description

Cooperative programme involving Western Plains Zoo, Queensland University and the Conservation Commission of the Northern Territory. External funding will be sought from the Australian Gas Company, and the Marsupial Conservation Breeding CRC to support this work. Budgets will not be prepared until details of the projects scope are finalised.

5. TRANSLOCATION TO OFFSHORE ISLAND

5.1 Feasibility study of translocation of mainland form to offshore island

(a) Description

Involves intitial work by RS from CCNT and CALM in formulating a discussion paper addressing issues relating to translocation of the mainland form of the Mala to an offshore island. This document would subsequently be circulated to recovery team members for comment and review. The final document would be the basis for short listing island release site options.

(b) CCNT & CALM Contributions

Salaries: 0.05 x RS x 2	$ 4 000
Mail, phone & facsimile costs:	$ 200
Consumables: (production costs etc..)	$ 100
Total	**$ 4 300**

(c) ESP Funds Required	**NIL**

(d) Total Cost of Action	CCNT & CALM	$ 4 300
	ESP Funds	NIL
	Total	**$ 4 300**

5.2 Selection of suitable offshore island

(a) Description

Detailed information would be compiled on islands shortlisted as potential sites for reintroduction of mainland Mala. Trips would be undertaken to favourable island sites to confirm the existance of suitable habitat characteristics for translocated Mala and the logistics of transferring and monitoring animals. Staff from both CCNT and CALM would be involved in these trips which would require 30 (10 x 3) days to complete. Boat charter and or fuel expenses would be incurred in travel to most islands sites.

(b) CCNT & CALM Contributions

CALM	
Salaries: RS @ $250/day x 10	$ 2 500
TO @ $250/day x 10	$ 1 400
CCNT	
Airfares: (Alice Springs - Perth - Alice Springs) x 1	$ 680
Total:	**$ 4 580**

(c) ESP Funds Required

CCNT	
Salaries: RS	Action 1.2
CALM	
Field Allowance: @ $36/night x 30	$ 1 080
Vehicle running costs: ^ 5 000 km @ 25c km	$ 1 250
Diesel fuel &/or boat charter	$ 3 000
Total	**$ 5 330**

(d) Total Cost of Action	CCNT & CALM	$ 4 580
	ESP Funds	$ 5 330
	Total	**$ 9 910**

5.3 Translocation to offshore island

(a) Description

Animals for translocation to the selected island site would be transported by air from Alice Springs accompanied by CCNT staff. CALM staff from Perth would travel by road to the nearest port site. Translocation requires 36 days (12 x 3 days) work (involving care of transferred animals, release and radio tracking) at the site with a RS from both CCNT and CALM and an ESP funded TO. Follow up monitoring of the released animals would be conducted by CALM and require 56 days (28 x 2). Analysis and reporting of the translocation and monitoring would be conducted by CALM using ESP funded TO.

(b) CCNT & CALM Contributions

CALM	
Salaries: RS @ $250/day x 40	$10 000
CCNT	
Radio-telemetry collars & equipment	$10 000
Airfreight: 30 x 1.5kg animals @ $3.50/kg	$ 160
Transport Cages: 15 @ $20/cage	$ 300
Total	**$20 460**

(c) ESP Funds Required

CCNT	
Salaries: RS	Action 1.2
CALM	
Salaries: TO	$28 000
Administration on-cost	$ 5 600
Field Allowances: @ $36/night x 92	$ 3 320
Vehicle running costs: 10 000km @ 25c/km	$ 2 500
Diesel fuel &/or boat charter	$ 5 000
Total	**$44 420**

(d) Total Cost of Action	CALM & CCNT	$20 460
	ESP Funds	$44 420
	Total	**$64 880**

* 1 year full funding for translocation then subsequent monitoring incorporated in CALM programmes and island monitoring.

6. TRANSLOCATION ON MAINLAND

6.1 Translocation to Heirsson Prong/Peron Peninsula,
6.2 Selection of additional release sites, and
6.3 Translocation

(a) Description

Translocation to new sites on the Australian mainland is the long term goal of the recovery plan. The selection of sites will be greaty influenced by current programmes and future developments in feral animal control and habitat restoration. Budgets will be prepared and ratified by the recovery team well in advance of proposed start dates.

7. RECOVERY TEAM ADMINISTRATION

(a) Description

The Mala recovery team is represented by personnel from a broad geographic range and substantial travel costs are involved in conveneing full meetings of the group on a regular basis. Airfare support is required to ensure that CCNT and CALM representatives can meet to review the progress of recovery actions at least twice annually. This would involve provision of funds for 4 x return airfares between Alice Springs and Perth with the venue of the meeting rotating between the two centres. All other administration costs for the Mala recovery team are borne principally by CCNT and CALM as the two active members of the teams core, this includes phone, facsimile, secretarial expenses (Adimin. Officer AO) and mailing cost.

(b) CCNT & CALM Contributions

Salaries: RO @ $250/day x 12 x 2	$ 6 000
AO @ $120/day x 4 x 2	$ 960
Phone & facsimile	$ 250
Mailing costs	$ 100
Total	**$ 7 310**

(c) ESP Funds Required

CCNT	
Salaries: RS	Action 1.2
Airfares: (Alice Springs - Perth - Alice Springs) x 2	$ 1 360
CALM	
Airfares: (Perth - Alice Springs - Perth) x 2	$ 1 360
Accomodation: @$100/night x 2	$ 200
Total	**$ 2 920**

(d) Total Cost of Action	CCNT & CALM	$ 7 310
	ESP Funds	$ 2 920
	Total	**$10 230**