Diagnosis of mammal decline in Western Australia, with particular emphasis on the possible role of feral cats and poison peas

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Front cover:

© Photos of Bullock Poison *Gastrolobium trilobum* (from Gardner and Bennetts 1956), and a feral cat provided by Jiri Lochman, Lochman Transparencies.

Executive Summary

South-west Western Australia is regarded as a hotspot of world biodiversity but has lost much of its distinctive mammal fauna in the brief 180 year period since European settlement. The causes of such losses are contentious and the lack of a firm diagnosis of decline has hampered reconstruction efforts. In particular, there appears to have been an early loss of mammals prior to 1900 of unknown cause. This was at a time when the European population of Western Australia was *c.* 53,000 in 2.5 million km^2.

We have sourced the notes and letters of an early mammal collector, Guy Shortridge, to provide additional information on the timing and pattern of decline of mammals in the first 75 years of European settlement in Western Australia. His detailed letters from the period 1904-07 have been transcribed as part of this grant and are soon to be published. His views, as expressed in his letters, have prompted a re-examination of the likely causes of decline. The temporal and spatial patterns of decline were juxtaposed against new evidence for the colonisation of the area by feral cats *Felis catus* and the intensity of pastoral and agricultural settlement.

Feral cats became established throughout arid Western Australa in the 1870s – 1890s, consistent with the time of loss of mammals in these regions. However, cats radiated out from coastal settlements from as early as the 1840s with no apparent impact in mesic areas of southern Western Australia. This anomaly could mean that feral cats were not responsible for mammal losses, or it might mean that some factor or factors operate to ameliorate the impact of cats in more mesic parts of southern Western Australia. This study explores possible mechanisms that might explain why feral cats may have been effective in eliminating native mammal species in some areas, but not from other areas.

A satisfactory link between the establishment of feral cats and the decline of fauna requires the susceptibility of native fauna to vary geographically, with native species being most susceptible in arid areas and least in mesic areas. We hypothesised that the presence of either dense cover and/or plants of the genus *Gastrolobium* (plants of the pea family that are highly toxic to exotic species but not to native animals) in mesic areas may have protected native species from the impact of cat predation. No such protection was likely to be available in arid and semi-arid areas.

Many *Gastrolobium* species are highly toxic to exotic mammals (and to exotic carnivores via secondary poisoning) and may have limited the ability of cats to establish populations in locations where they form a major part of the understorey vegetation. In

contrast, native mammals that have co-evolved with *Gastrolobium* show high tolerances. Feral cats are believed to have eliminated native species of mammal from many islands around Australia, but examples of co-existence typically involve islands with a mesic climate and dense understorey vegetation. Hence, these two factors, dense *Gastrolobium* and/or dense understorey vegetation, may have acted to protect native mammals from predation from feral cats in some areas.

We revisited Shortridge's collecting locations to determine whether sites that were formerly rich in fauna were also sites with dense stands of *Gastrolobium* or other understorey, and, conversely, that sites formerly poor in native fauna were sites that had few poison peas and sparse understorey. Such a correlation would lend weight to the hypothesis that feral cats may have been responsible for early declines of native mammals. We found that Shortridge's collecting sites differed greatly in incidence of poison plants and vegetation density in a way that was consistent with the hypothesis that the impact of feral cats may have been significant in arid and semi-arid areas and greatly ameliorated in more mesic areas.

We bolstered this analysis with a re-examination of survey data from the Western Australian wheatbelt from the 1970s to see if the incidence of *Gastrolobium* or the extent of vegetation cover could explain patterns of species richness of mammals across the region. Our re-analysis of the species richness of mammals in wheatbelt reserves, isolated by extensive land clearing in the 1960s, suggested that while size of reserve was the most important determining factor, incidence of poison peas *Gastrolobium* increased the number of species present for a given area by as much as 25%. In addition, the persistence of remnant populations of mammals away from the coastal margins of south-west Western Australia is strongly linked to sites with abundant poison peas of species with relatively high toxicity. Examples include surviving populations of threatened mammals at Dryandra, Perup and Batalling Forests and Tutanning and Boyagin Nature Reserves.

The loss (or near loss) of species from many of these sites in the 1970s coincided with a dramatic reduction in available habitat and the loss of the likely buffering role of poison peas that formerly occurred in these cleared areas. These would have acted in addition to the factor typically suggested to explain these losses (the reduction in use of '1080' poison for rabbit control following introduction of the European rabbit flea in 1969 to facilitate the spread of myxomatosis, resulting in an increase in European fox *Vulpes vulpes* populations).

The persistence of mammals in coastal areas and in wet gullies in the forest zone appears to be linked to dense vegetation providing a refuge from predators. In some sites in the forest zone, thickets of Heart-leaved Poison *Gastrolobium bilobum* are likely to provide dual protection from predation (physical protection as well as secondary poisoning of exotic predators).

Finally, we attempted to establish what this proposed linkage between loss of mammals, predation by colonising feral cats, and the role of *Gastrolobium* in ameliorating that predation in some areas might mean for current attempts to conserve native mammals in southern Australia.

Management implications

This synthesis of historical ecology and present-day field ecology suggests a number of recommendations to assist current conservation efforts of threatened mammals in southern Western Australia. These include suggestions to:

- Facilitate improved predator management at fauna recovery sites by placing greater emphasis on the management of feral cats;
- Facilitate improved predator management at fauna recovery sites through the greater use of understorey plantings of *Gastrolobium* as a buffer around key fauna recovery sites;
- Place greater emphasis on the inclusion of poison peas *Gastrolobium* in replanting for salinity control and habitat reconstruction. This might apply particularly to non-farmer groups involved in replanting;
- Facilitate improved predator management at fauna recovery sites, particularly of feral cats, through the use of harvested seed of highly toxic species such as Heart-leaved Poison *G. bilobum* in feeders for reintroduced species to create 'toxic wildlife';
- Identify new opportunities to re-establish mammal fauna through improved knowledge of the 'toxic load' of the landscape to exotic predators due to the presence of *Gastrolobium*;
- Conserve some *Gastrolobium* species by greater education of farmers about the minimal risk to stock posed by those species of *Gastrolobium* that rely largely on physical defences against herbivory rather than high levels of toxin;
- Buy back farming properties adjoining key reserves to restore vegetation, including a major understorey of *Gastrolobium*;

- Re-evaluate the current policy of fire suppression in wheatbelt nature reserves, given the established link between fire and regeneration of thickets of *Gastrolobium*; and
- Limit the opening up of remaining areas of dense bushland on the coastal fringes (by construction of roads or tracks, by excessive fire, or by further clearing), which may threaten remnant populations of native mammals by allowing incursions by exotic predators.

Introduction

Eighteen species of Australia's unique mammals are believed extinct and another 40 are considered under threat. The key factors responsible for these losses are contentious and have been debated for many decades. Historical ecology has much to contribute to our understanding of the causal factors involved. Recent analyses of historical data such as bounty payment records from New South Wales (Short 1998) and previously unpublished reports of museum collectors (Short and Calaby 2001) have provided new insights into the role of introduced predators, particularly European Red Foxes *Vulpes vulpes*, in the demise of our mammal fauna. This research has led to changes in on-ground management of endangered species throughout Australia and to the successful re-introduction to the mainland of species that had only survived on off-shore islands (Short and Turner 2000, Richards and Short 2003).

One of the key historical sources for assessing the timing and spatial pattern of decline of the native fauna of Western Australia is the work of Guy Shortridge. He collected extensively in southern Western Australia in the period 1904-07. His work provides vital information on the timing of decline of mammal species and how that decline varied across land-use regions. Shortridge published annotated lists of the species that he collected (Shortridge 1909, 1936), but his letters have never been collated or published. These potentially provide further insight into the key factors he believed responsible for declines.

He commented on the lack of mammals at many of the locations at which he collected, but was able to locate some areas where substantial populations of mammals persisted. For example, there was a band of country to the east of the Avon River in what is now the wheatbelt where he collected a rich suite of mammals, many of which were the last to be collected on the mainland.

We believe that by comparing the environmental attributes of the sites where Shortridge collected, we will be able to reinterpret the cause of loss of mammals. In particular, we suspect that Shortridge's rich collecting areas may be those with exceptionally high densities of the native poison pea plant *Gastrolobium* spp. This genus is highly toxic to exotic herbivores and predators (the latter via secondary poisoning). If this is the case, then it suggests that either predation from feral cats (established in the region in the mid-1800s) or the exclusion of stock may have been the key factor in the early loss of mammal species from Western Australia.

National Geographic funding has contributed to three outcomes:

- the collation, transcription and publishing of Shortridge's letters to the curator of mammals at the British Museum of Natural History;

- an examination of the characteristics of sites where Shortridge collected, comparing and contrasting sites with many mammals and sites with few mammals; and
- re-examination of mammal survey data from the 1970s in wheatbelt reserves to establish whether the presence of poison plants is linked to species richness of mammals.

Methods

Shortridge's letters

We sourced Shortridge's unpublished letters from the British Museum of Natural History in London and the Battye Library in Perth, Western Australia. These were transcribed and key quotes relating to fauna, collecting techniques, and impressions of land use and the impact of that land use were extracted. Additional archival material on Shortridge was sourced where possible.

We also collated historical statistics on sheep numbers and settlement patterns for the early 1900s by district in an attempt to understand what factors may have been operating at that time. We were particularly interested in comparing trends of decline in mammals between districts and juxtaposing these trends against trends in land use and stock numbers. Transcriptions, observed spatial and temporal patterns of decline, and data on land use were detailed in a manuscript that is about to be published in the journal *Australian Zoologist* (Short in press).

Shortridge's collecting localities

Shortridge collected at *c.* 25 localities in five broad regions in southern Western Australia over a 3-year period. Sites were spaced over a 1200 km^2 transect between Carnarvon in the arid north and Albany in the mesic south. Sites can be broadly grouped into mesic forest and coastal scrub, mesic woodland, arid pastoral, and arid non-pastoral. We aimed to revisit these sites nearly 100 years on to assess the distribution and abundance of poison plants, vegetation cover and height diversity, and abundance of non-native mammals (European rabbit *Oryctolagus cuniculus*) to see if they differed substantially between collecting localities in a way that might shed light on the historic cause of decline of mammals.

Re-examination of mammal survey data

In the 1970s the Western Australian Museum conducted detailed surveys of 23 nature reserves in the wheatbelt of southern Western Australia. All were reserves isolated from each other and from other bushland by a recent prior expansion of farmland. Surveys collected detailed information on fauna, including mammals, and also of vegetation. Mammal species richness in the reserves was explained by reserve size, which explained 72% of the observed variation (Kitchener *et al.* 1980). Simply put, the smaller the reserve, the less mammals occurred, with even the largest having a reduction of species richness from that likely to have been present at the time of Shortridge's surveys. The addition of other reserve variables, such as number of plant species, number of vegetation associations, or number of vegetation structural classes did not significantly increase the amount of explained variation.

Detailed information was collated in individual publications on each reserve and from these it was possible to collate the incidence of poison plants in survey transects as well as an estimate of vegetation density. We collated information from site descriptions and from the appendices giving plant species lists for each site. We also collated information on vegetation density in three strata (understorey, mid-storey and canopy), annual rainfall, area of woodland and area of heath/shrub/mallee habitat, and computed Shannon-Wiener Index of habitat diversity.

Additional data for two reserves (Tarin Rock and Tutanning Nature Reserves) were added to this data set. Tarin Rock Nature Reserve was surveyed by the Western Australian Museum, but data from this reserve was omitted from the original analyses, as the reserve was extensively burnt between the two surveys conducted by the Museum. We have collated additional data on the mammals of Tarin Rock to bolster their species list. Tutanning Nature Reserve is very close to one of Shortridge's original collecting locations (Woyerling Spring (= Woyaline) is 5 km east of Tutanning) and its mammal fauna was known from work conducted at about the same time as the Museum surveys (Sampson 1971). No comparable survey of the vegetation was available from the 1970s, but data on the incidence of poison plants and vegetation density was collected for this study as part of the survey of Shortridge's locations.

Our analysis differs also from the original analysis by Kitchener *et al.* (1980) in that we have chosen to include their data from Badjaling Flora Reserve. This data was omitted in the previous analysis as it appeared to be an outlier (only one species of mammal was recorded despite a sizeable area of 245 ha). However, we believe the extreme isolation and the long history of clearing may have contributed to this low species complement.

The areas of reserves were log-transformed prior to analysis and percentages were transformed by taking the square root (after the addition of 0.5 and division by 100).

Results

Shortridge's letters

Proofs of a paper to be published in *Australian Zoologist* (Short in press) are presented in Appendix 1. These include excerpts from Shortridge's letters to Oldfield Thomas, curator of mammals at the British Museum of Natural History. The locations at which Shortridge collected and the route of his travels are detailed in Figure 1.

Four important generalisations can be made about the pattern of decline of the fauna from Shortridge's collections:

i. An absence of all but a few terrestrial mammals in the arid and semi-arid zones. This decline appeared to be common to both pastoral (Carnarvon and Clifton Downs) and non-pastoral districts (Southern Cross, Kalgoorlie, and Laverton).

ii. An abundant and species-rich fauna extant in at least some areas of the mesic south-west (Arthur River, near Wagin, east of Beverley and Pingelly, Albany and Margaret River, to the south-west of Busselton).

iii. A lack of fauna in the immediate vicinity of areas in the mesic south-west where agriculture was well developed (Northam, York, and Beverley).

iv. Regional patterns of decline which were broadly consistent for both marsupials and native rodents. In contrast, bats and the one species of monotreme remained abundant.

Shortridge identified a major decline in the arid and semi-arid zone fauna that appeared to be general to all terrestrial species other than the large kangaroos *Macropus* spp., echidna *Tachyglossus aculeatus*, and to some extent, the bilby *Macrotis lagotis*. He noted the contraction of brush-tailed possums *Trichosurus vulpecula* (Plate 1) and bilbies from the semi-arid zone in the years immediately prior to 1906 (Shortridge 1909), specifically mentioning the loss of possums from the Carnarvon district. His accounts are broadly consistent with the observations of Facey (1981) and Richards and Short (1996) in the arid zone at about the same time.

The past decline of mammals in arid and semi-arid parts of Western Australia detected by Shortridge was not evident at sites he visited in mesic woodland, scrub and forest sites, except in areas of closer settlement. In fact, he found that many species, soon to be extinct on the mainland, were so abundant as to be pests when trapping at woodland sites. For example, Shortridge reported that the brush-tailed bettong *Bettongia penicillata* "simply swarms about twenty miles east of Pingelly", the burrowing bettong *B. lesueur* was regarded as "very plentiful in most districts", the tammar wallaby *Macropus eugenii* was "the most widely-distributed wallaby …[and] collect together in large numbers", and the possum *Trichosurus vulpecula* was "abundant and generally distributed" (Thomas 1906b). The bilby and the echidna were two of the few species to occur in both semi-arid and more mesic areas. The former was described as "more plentiful near the coast … [and] to have become scarcer in the interior than formerly"; the latter as more numerous in the semi-arid interior (Thomas 1906b).

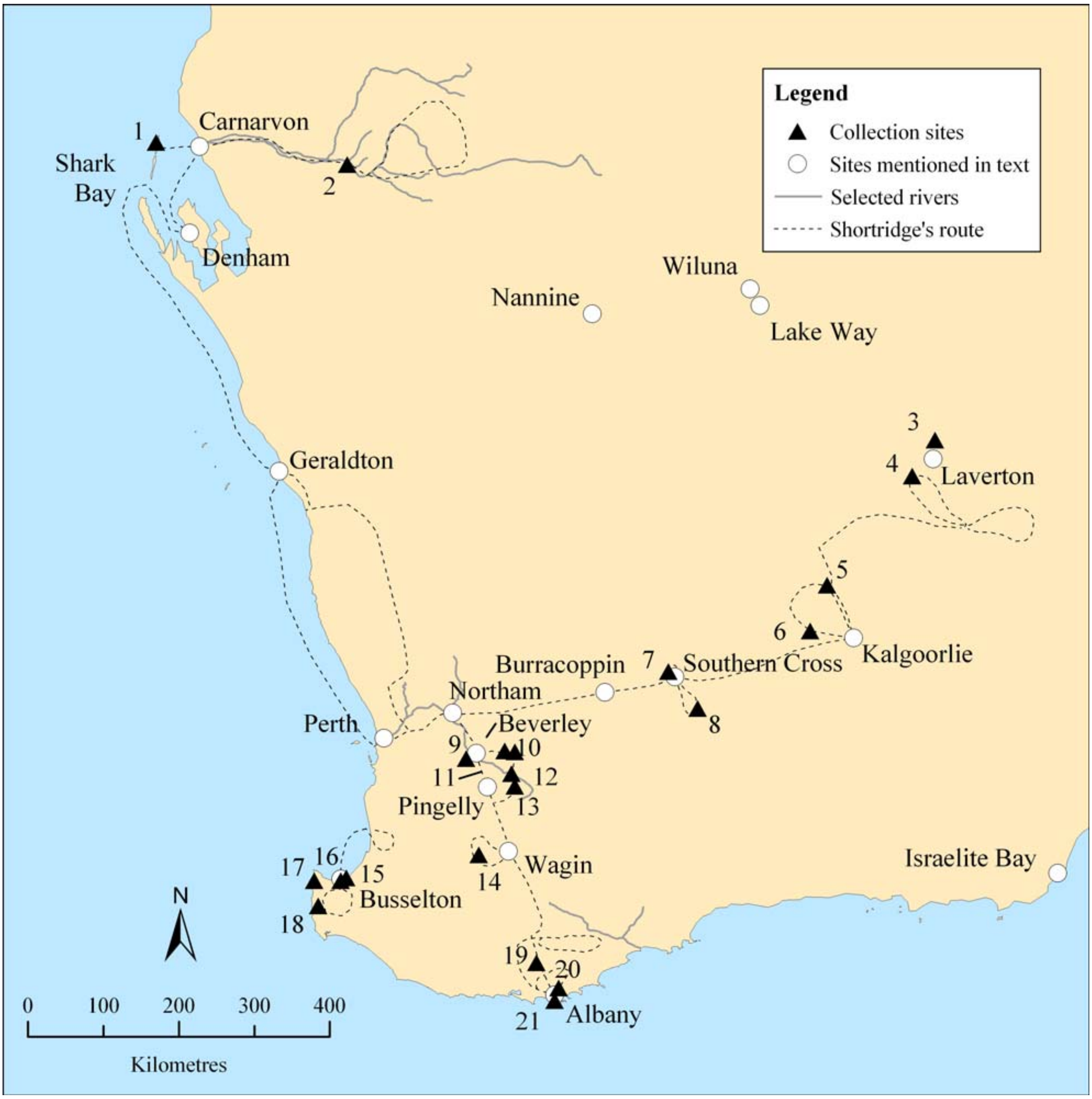
Plate 1: Brush-tailed possum *Trichosurus vulpecula.* Photo © Jiri Lochman, Lochman Transparencies.

These observations are consistent with those of other observers (Facey 1981), who described the taking up of new country in 1902 in an area some 30-50 km south of Shortridge's collecting locality at Woyaline, the presence of burrowing bettong at Cranbrook in 1907 (Kitchener and Vicker 1981), at Kulyaling (halfway between Pingelly and Brookton) at some time after 1908 (P. Hall, pers. comm. to J. Short 1988), at Mukinbudin (170 km north-east of Northam) in 1910 (Friend 1991), at Gracefield (34 km south-east of Kojunup) in 1913 (Kitchener and Vicker 1981), and at Pingelly in 1942 (Kitchener and Vicker 1981).

Shortridge frequently cited the need to move well away from towns and farmland to obtain specimens. He recorded the hunting of native species as pests, for food, and for the sale of their skins, and clearing, cultivation, fire, and the impact of domestic dogs and cats.

Shortridge collected native rodents at many sites (water-rat *Hydromys chrysogaster* at Albany and Beverley, bush rat *Rattus fuscipes* at Albany, hopping mouse *Notomys mitchelli* at Stockpool, Dwaladine and Woyaline, and ash-grey mouse *Pseudomys albocinereus* at Stockpool and Dwaladine), but comments on their scarcity or absence at more semi-arid sites (e.g. Parkers Range, Jaurdi Hills, Laverton, and Clifton Downs) despite considerable effort spent in searching for them. Hence, both marsupials and native rodents appeared to show similar patterns of decline. Susceptibility to declines and extinctions appeared not to be taxonomically based (i.e. marsupial versus placental).

Figure 1: Map of the southern Western Australia showing sites mentioned in Short (in press) (○) and Shortridge's collection sites (▲) and route. 1 – Bernier Island; 2 – Clifton Downs; 3 – North Pool; 4 – Hawks Nest; 5 – Kurrawang; 6 – Jaurdi Hills; 7 – Crookerdine Lake; 8 – Parker's Range; 9 – Boyadine; 10 – Stock Pool; 11 – Dwaladine; 12 – White Well; 13 – Woyaline Well; 14 – Arthur River; 15 – Wonnerup; 16 – Beachlands; 17 – Yallingup; 18 – Margaret River; 19 - Mt Barker; 20 – King River; 21 – Big Grove. Shortridge's route in Western Australia is shown from a map accompanying one of his letters.



Shortridge's collecting sites – do they provide clues to the cause of declines and extinctions of mammals?

We visited many of Shortridge's collecting sites in 2003-04 (Table 1) to assess the incidence of poison plants, vegetation density and the density of one introduced species – the European rabbit. The sites that we visited are mapped in Figure 2.

We collated records of poison plants (*Gastrolobium* spp.) in the Western Australian Herbarium (Figure 3). This figure indicates a broad distribution for *Gastrolobium* spp. across southern Western Australia. We plotted incidence of poison plants versus vegetation density at sites we visited (Figure 4a). This indicates very large differences between location in both incidence of *Gastrolobium* and in vegetation density. Sites in the mesic woodland (sites 1-8) typically had a high incidence of *Gastrolobium* (Plate 2). Sites in mesic shrubland near Albany (sites 18-23) had no *Gastrolobium* but a very high density of vegetation (Plate 3). Sites in the arid pastoral (sites 9-11) and arid non-pastoral (sites 12-17) had a low density of perennial vegetation and little or no *Gastrolobium* (Plate 4).

Plate 2: Mesic woodland vegetation at Landscape Hill Nature Reserve, November 2003.

Plate 3: Dense mesic shrubland vegetation at Bon Accord Nature Reserve, November 2004.

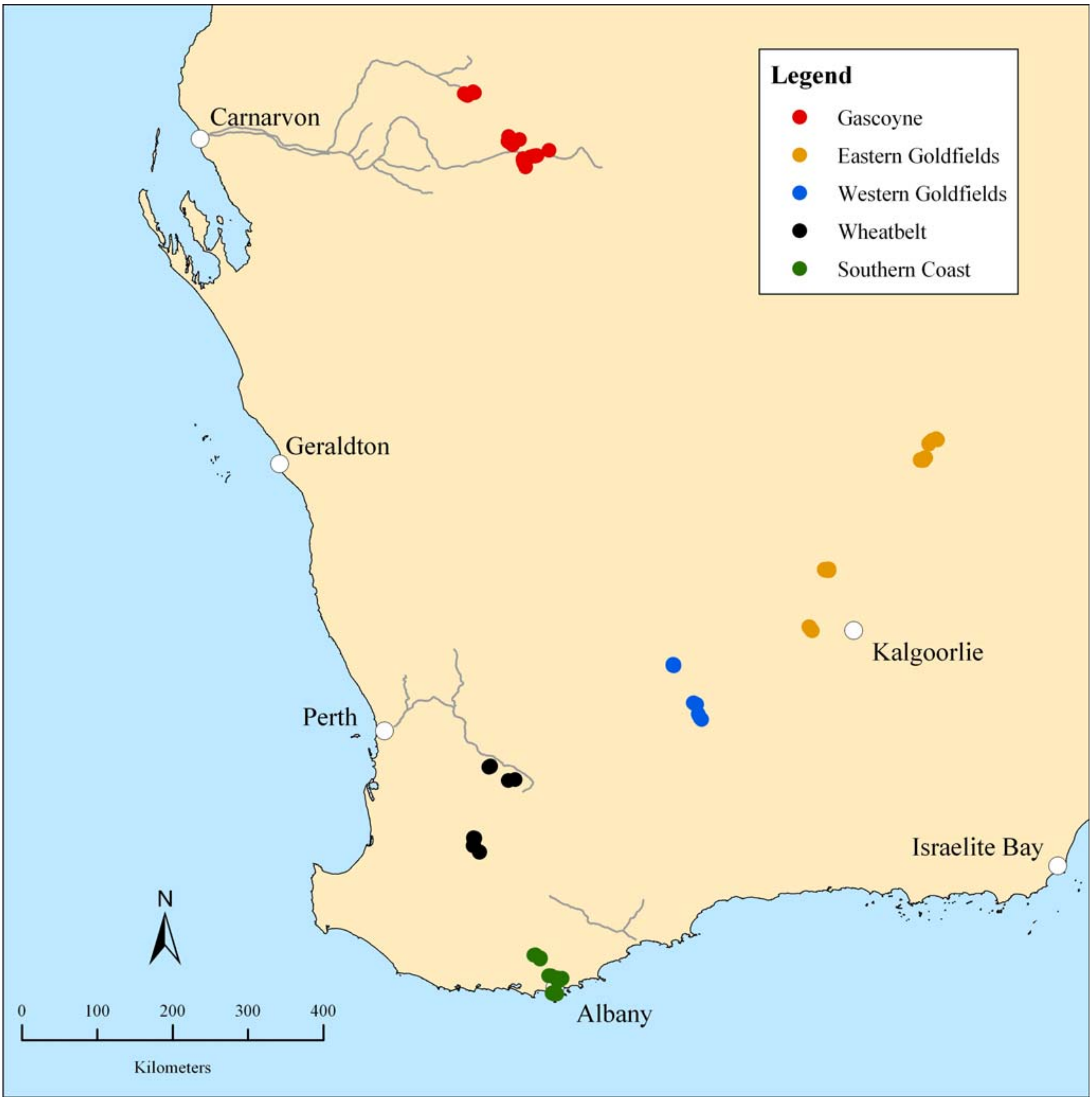
Plate 4: Low density perennial vegetation at Jaurdi Hills in the arid non-pastoral zone, September 2004.

The presence of rabbits was recorded on survey transects (Table 2). Rabbits were recorded on 45.5% of transects in dense coastal shrubland at Albany, on 17.3% of transects in the Goldfields, at 8.8% of transects in the wheatbelt, and at 4.8% in the Gascoyne. Edaphic and climatic factors are likely to be the major factors determining their presence. *Gastrolobium* were present at wheatbelt sites in 67% of transects and at two sites (10%) at Parker Range in the western Goldfields. They were not recorded on transects at Albany, Goldfields sites other than Parker Range, and Gascoyne sites. There was no significant association between the presence of *Gastrolobium* and the presence or absence of rabbits (Table 3) using a combined data set for those locations with both rabbits and *Gastrolobium* present (wheatbelt locations and locations around Southern Cross).

Six species of *Gastrolobium* were recorded in wheatbelt sites, with between zero and three species per site (0 species = 13 sites (19%); 1 = 32 (48%); 2 = 18 (27%); 3 = 4 (6%)). The most abundant species was Box Poison *Gastrolobium parviflorum* (40 sites, 60%), followed by Bullock Poison *G. trilobum* (16 sites, 24%), Prickly Poison *G. spinosum* (13 sites, 19%), Boat-leaved Poison *G. obovatum* (7 sites, 10%), York Road Poison *G. calycinum* (3 sites, 4.5%), and Heart-leaved Poison *G. bilobum* (1 site, 1.5%; Plate 5). Two species, *G. spinosum* and Wodjil Poison *G. floribundum*, were recorded at Parker Range in the western Goldfields.

Plate 5: Heart-leaf Poison *Gastrolobium bilobum*. © Jiri Lochman, Lochman Transparencies.

Figure 2: The 23 locations surveyed as part of this study. We attempted to sample sites as close as possible to sites sampled by Shortridge in 1904-07, almost 100 years earlier. Details of the sites are given in Table 1.



Re-examination of mammal survey data

The locations of reserves sampled by the Western Australian Museum in the wheatbelt in the 1970s are given in Figure 5. Details of reserve area, the poison peas recorded, the toxicity of the dominant species, and the frequency at which the species was recorded are given in Table 4. We plotted the number of mammal species for each reserve against log of area (hectares) for 25 reserves (see Appendix 2 for data). This gave a significant regression of y = 3.73 LogArea -5.12 (r^2 = 67.4; $F_{1, 23}$ = 50.53, p < 0.001). We used this equation (Figure 6a) to calculate the estimated species richness of each reserve based on area and subtracted this from the actual species count (residual variation). This difference was then regressed against the percentage of transects containing poison peas in each reserve. The percentage of transects with poison peas in each reserve was a significant predictor of this variation between observed and predicted (y = 0.0294 % poison -0.415 (r^2 = 19.4; $F_{1, 23}$ = 6.79, p = 0.016)). Sites with an abundance of poison peas had as many as three additional species for a given area of reserve (Figure 6b). Key outliers were West Bendering and Tutanning Nature Reserves, which had significantly more species than expected from the area of the reserve, and Buntine Nature Reserve and Badjaling Flora Reserve, which had nearly three species less than expected from the area of reserve.

A multiple regression equation for number of mammal species as a function of reserve area and percentage of poison plants was highly significant (y = 3.385 LogArea + 0.0302 % poison – 4.69; $F_{1, 22}$ = 34.35, p < 0.001), explaining 73.5% of the variance. The addition of understorey or mid-storey vegetation density (percentage of transects with > 30% vegetation cover) did not improve the predictive power of the equation.

The Western Australian Museum surveys were conducted at the end of a period of intense land clearing in the Western Australian wheatbelt. The area of native vegetation surrounding reserves was greatly reduced over a period of 10 years prior to the surveys (Table 5). The amount of remnant vegetation at many sites was reduced by more than 50% in the *c.* 10 year period prior to fauna surveys, with overall landscape cover of remnant vegetation reduced to < 10% at 17 of 22 sites for which data are available. Hence, it might be expected that the faunal complement of the reserves would decline over time through the process of species ‘relaxation’ (the fauna at the time of assessment may have been out of equilibrium with the amount of vegetation left after land clearing). However, another factor contributing to a further loss of fauna would be the diminished role of *Gastrolobium* (as so much of it would have been lost from this cleared land) in excluding exotic predators via secondary poisoning.

Both factors are likely to contribute to an 'extinction debt' for the modified landscape (Tilman *et al.* 1994).

Figure 7 shows the relative abundance of *Gastrolobium* spp. in southern Western Australia, as assessed from the Western Australian Museum surveys of the 1970s and our surveys of Shortridge's collecting locations. This suggests that only a few locations in southern Western Australia have abundant *Gastrolobium* spp., somewhat in contrast to their widespread distribution across the region (Figure 3). The localities at which Shortridge collected many mammals (in mesic woodland) coincided with these areas where *Gastrolobium* was abundant.

Table 1: Field surveys to assess the abundance of poison peas at sites in the vicinity of Shortridge's collecting localities. NR = Nature Reserve, NP = National Park.

	Location	Transects surveyed	Month /year of survey	Habitat
	Wheatbelt – mesic woodland			
1	Landscape Hill NR	5	Nov 03	Woodland
2	Tutanning NR	29	Dec 04	Woodland, heath, shrubland
3	Tutanning NR annex	5	Nov 03	Woodland
4	Walton's	6	Nov 03	Woodland, heath
5	Weam NR	7	Nov 03	Woodland, lithic, mallee
6	Arthur River NR 19738	6	Nov 03	Woodland, mallee
7	Arthur River NR 19739	5	Nov 03	Woodland
8	Clifton Park	5	Nov 03	Woodland, lithic, shrubland
	Gascoyne – arid pastoral			
9	Mt. Clere – Lucy's bore	11	Aug 04	Shrubland, woodland
10	Waldburg Station	5	Aug 04	Shrubland
11	Mt Augustus NP	5	Aug 04	Shrubland
	Goldfields – arid non-pastoral			
12	Southern Cross – north	5	Sep 04	Shrubland
13	Parker Range	15	Sep 04	Woodland, shrubland, mallee
14	Jaurdi Hills	15	Sep 04	Woodland
15	Goongarrie	16	Sep 04	Shrubland, woodland
16	Hawk Nest	15	Sep 04	Shrubland
17	Laverton Downs station – North Pool	15	Sep 04	Shrubland
	Albany – mesic shrubland			
18	Bakers Junction NR	7	Nov 04	Woodland
19	Millbrook NR	5	Nov 04	Woodland
20	Bon Accord NR	6	Nov 04	Woodland, shrubland
21	Torndirrup NP	16	Nov 04	Woodland
22	O'Neill Rd NR	5	Nov 04	Woodland
23	Mt Barker townsite	5	Nov 04	Woodland
	Total	214		

Figure 3: The distribution of poison peas of the genus *Gastrolobium* from records of the Western Australian Herbarium (*c.* 2500 records of 69 species) indicating a broad and apparently even spread through south-west Western Australia, including the wheatbelt and the mesic forest zone to the west of the wheatbelt. *Gastrolobium* were much more sparsely distributed in the arid and semi-arid zone to the east and north of the wheatbelt.

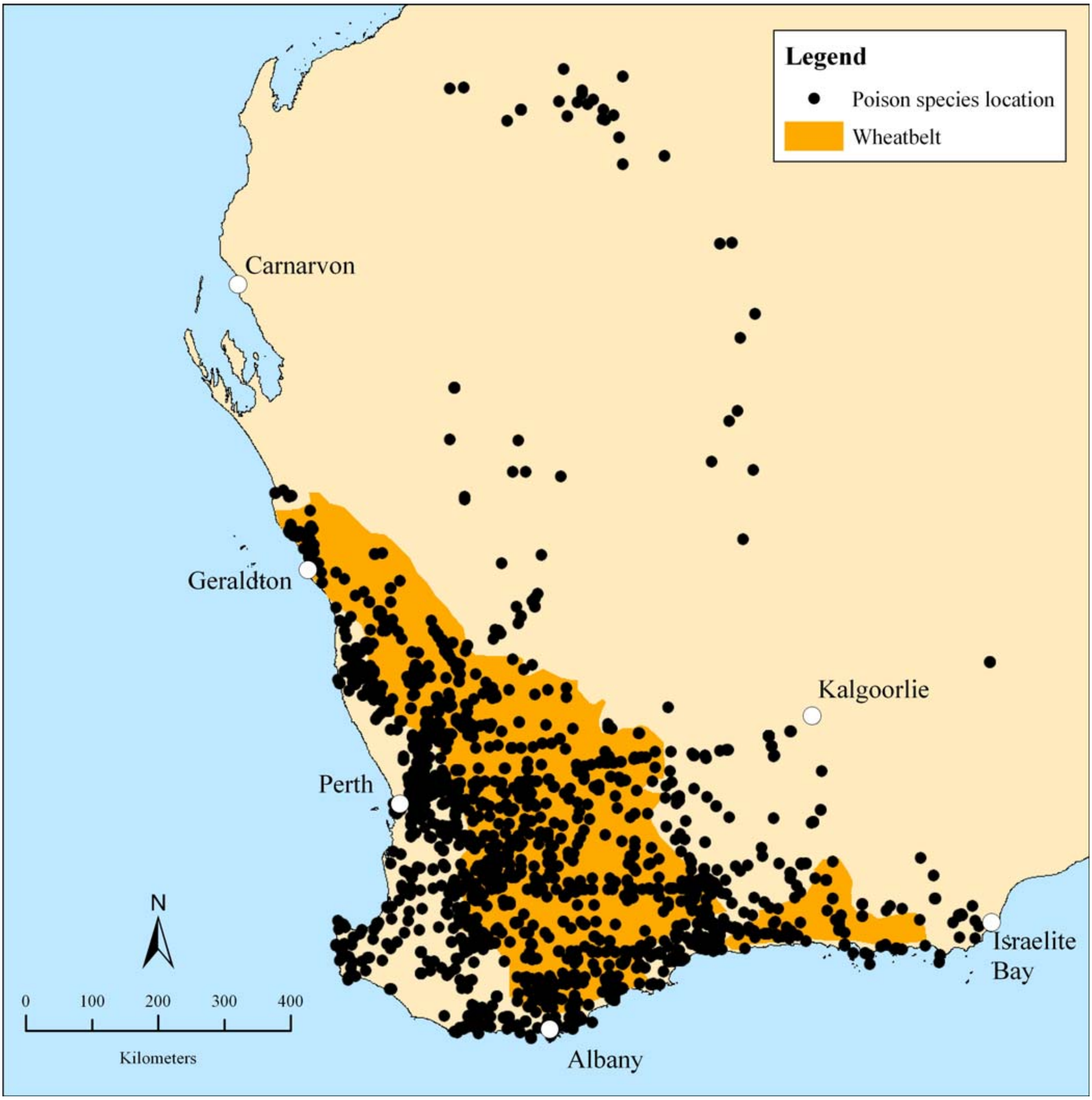
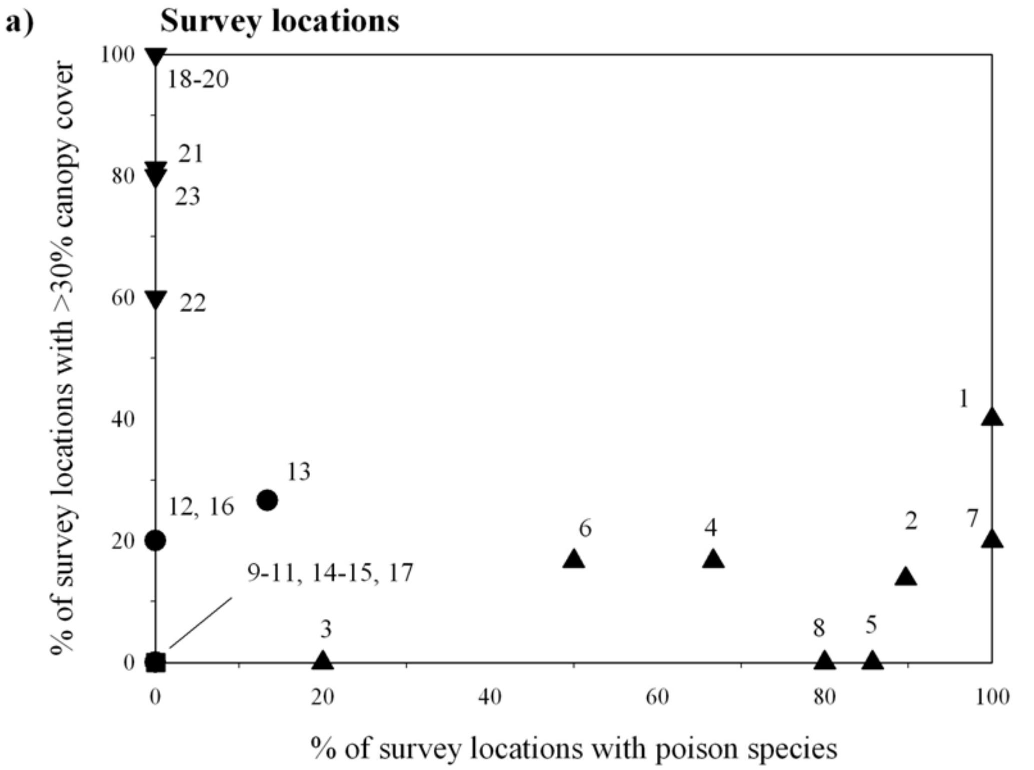


Figure 4: The incidence of poison peas *Gastrolobium* and dense understorey vegetation (> 30% canopy cover) at a) survey locations in Western Australia formerly visited by Shortridge in 1904-07 (▲mesic woodlands; ▼mesic shrublands; ■ arid pastoral; and ●arid non-pastoral); and b) sites in the Western Australian wheatbelt surveyed by the WA Museum in the 1970s. Location numbers in a) refer to locations listed in Table 1; location numbers in b) refer to locations listed in caption to Figure 5.



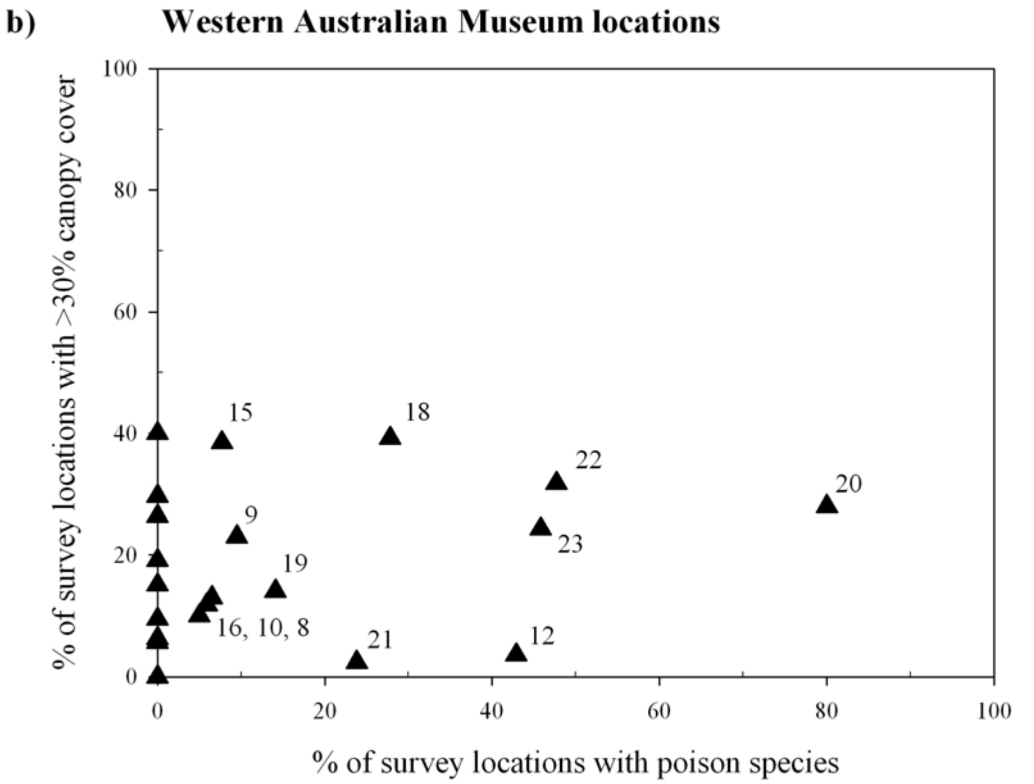


Table 2: Incidence of rabbit sign at Shortridge's survey locations as recorded in our surveys in 2003-04.

Location	No. of transects	Incidence of rabbit sign on transects (%)	Incidence of *Gastrolobium* on transects (%)
Wheatbelt - mesic woodlands	68	8.8	67.2
Albany – mesic shrubland	44	45.5	0.0
Gascoyne - arid pastoral	21	4.8	0.0
Goldfields – arid non pastoral (eastern sites only)	61	19.7	0.0
Goldfields - arid non-pastoral (Southern Cross-Parker Range)	20	17.3	10.0
Total	214		

Table 3a: Association between the presence of rabbit dung and *Gastrolobium* in same transect. Wheatbelt – mesic woodland

	Gastrolobium present	*Gastrolobium* absent	Total
Rabbits present	2	4	6
Rabbits absent	43	19	62
Total	45	23	68

Table 3b: Association between the presence of rabbit dung and *Gastrolobium* in same transect. Goldfields – arid non-pastoral (Southern Cross and Parker Range only

	Gastrolobium present	*Gastrolobium* absent	Total
Rabbits present	0	2	2
Rabbits absent	1	17	18
Total	1	19	20

Table 3c: Association between the presence of rabbit dung and *Gastrolobium* in same transect. Wheatbelt and Goldfields (Southern Cross and Parker Range) combined

	Gastrolobium present	*Gastrolobium* absent	Total
Rabbits present	2	6	8
Rabbits absent	44	36	80
Total	46	42	88

$\chi^2_1 = 2.62$, $p = 0.105$ (note, that one cell has expected probability < 5).

Figure 5: Location of sites surveyed by the Western Australian Museum for mammals in the 1970s. Sites were: 1 East Yuna; 2 Bindoo Hill; 3 Wilroy; 4 Marchagee; 5 Buntine; 6 East Nugadong; 7 Nugadong; 8 Billyacatting Hill; 9 Durokoppin; 10 East Yorkrakine; 11 Yorkrakine Rock; 12 Kodjkodjin; 13 North Bungulla; 14 Yoting Water; 15 Yoting Town; 16 Badjaling; 17 South Badjaling; 18 Bendering; 19 West Bendering; 20 Yornaning; 21 North Tarin Rock; 22 Tarin Rock; and 23 Dongolocking. Also included is the location of Tutanning Nature Reserve (24).

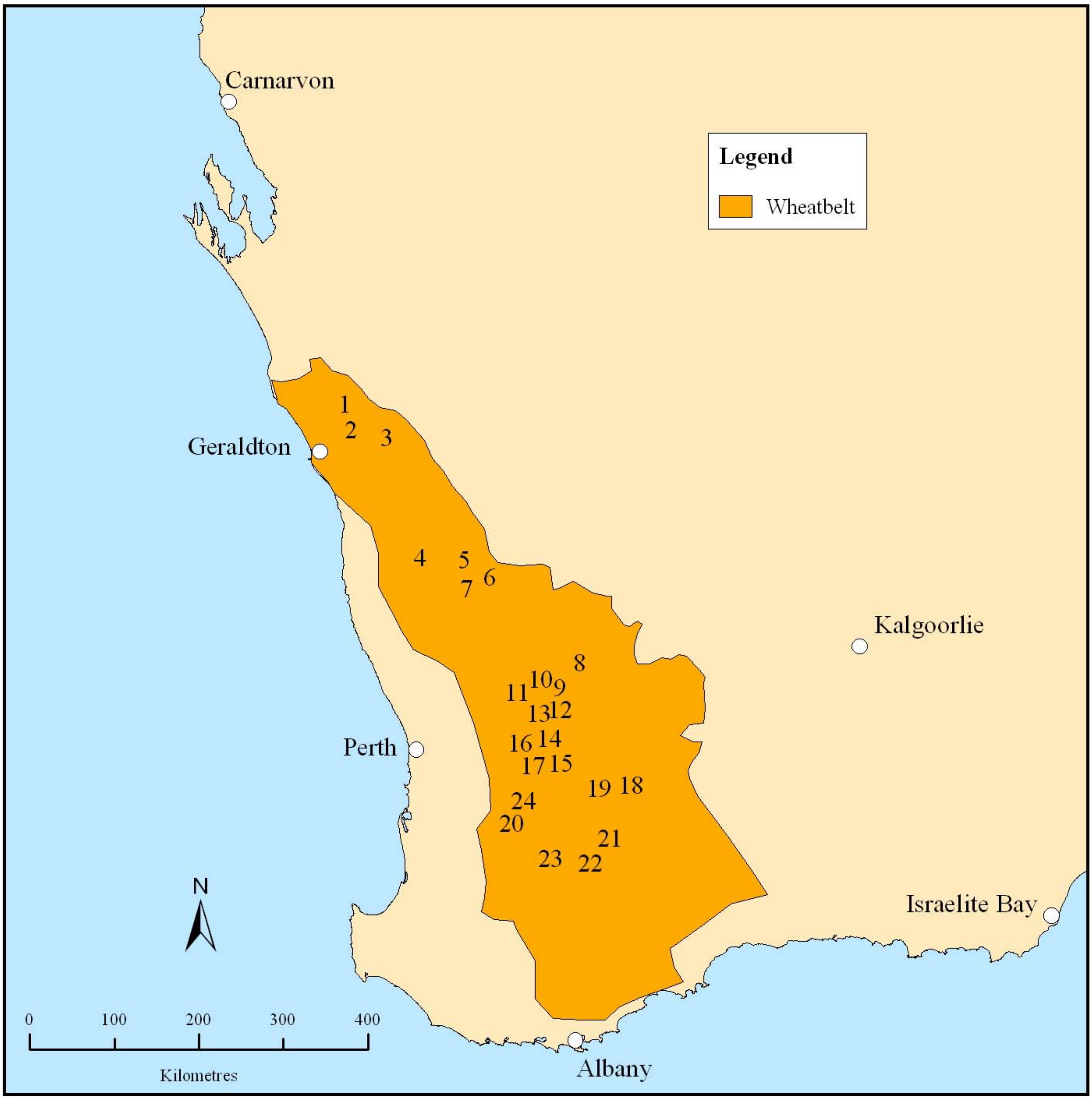
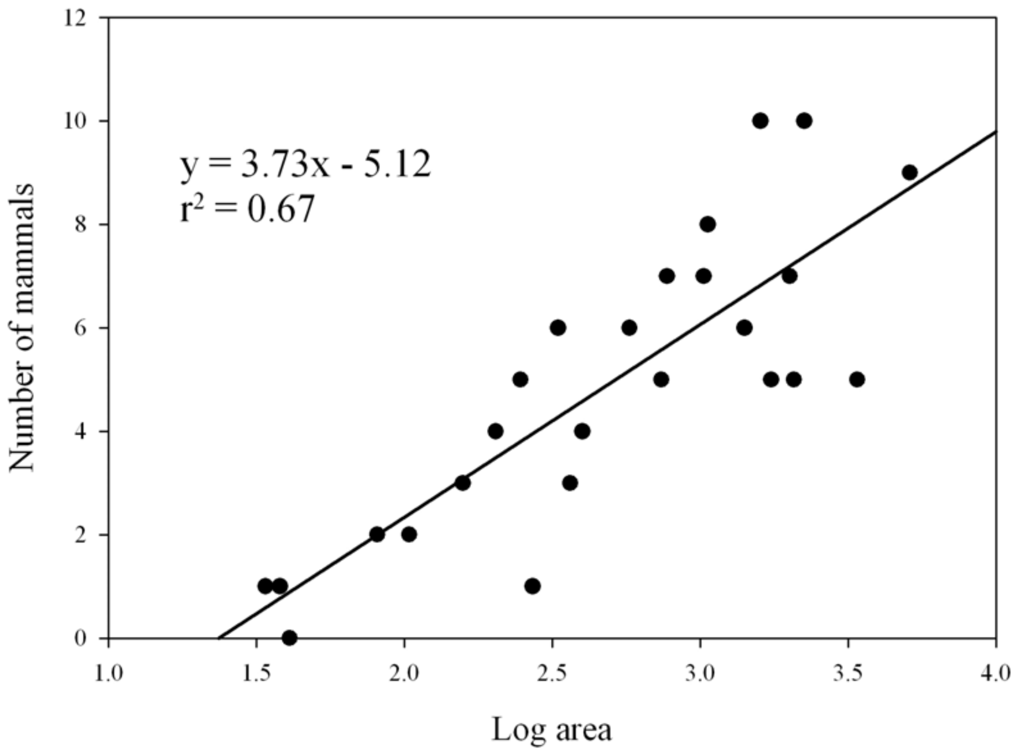


Table 4: Wheatbelt reserves, their area, species of *Gastrolobium* (in order of abundance in transects), likely poison content (high, medium or low of most abundant species), and percentage of transects on which *Gastrolobium* spp. recorded. Data are extracted from biological survey volumes commencing with Kitchener (1976) and summarised in Kitchener *et al.* (1980).

Reserve	Area (ha)	Species of *Gastrolobium*	Poison content	% occurrence
Yoting Water	34			0.0
Yoting Town	38	*G. crassifolium*	Moderate	7.7
South Badjaling	41			0.0
East Yorkrakine	81	*G. hookeri*	?	5.0
North Bungulla	104			0.0
Yorkrakine Rock	158			0.0
Kodj Kodjin	204	*G. crassifolium*, *G. hookeri*, *G. trilobum*	Moderate	42.9
Yornaning	247	*G. crassifolium*, *G. calycinum*, *G. hookeri*, *G. spinosum*	Moderate	80.0
Badjaling	272	*G. spinosum*	Low	5.9
Wilroy	331			0.0
Nugadong Forest	364			0.0
Nugadong	400			0.0
Marchagee	577			0.0
Bindoo Hill	740			0.0
East Nugadong	772			0.0
Durokoppin	1030	*G. crassifolium*, *G. trilobum*	Moderate	9.5
Dongolocking	1061	*G. crassifolium*, *G. spinosum*, *G. trilobum*, *G. tricuspidate*, *G. hookeri*, *G. laytonii*	Moderate	45.8
North Tarin Rock	1415	*G. crassifolium*, *G. trilobum*	Moderate	23.8
West Bendering	1602	*G. crassifolium*, *G. hookeri*, *G. spinosum*	Moderate	14.1
East Yuna	1740			0.0
Tarin Rock	2011	*G. spinosum*, *G. trilobum*	Low	47.7
Billyacatting Hill	2075	*G. spinosum*, *G. crassifolium*	Low	6.5
Tutanning	2250	*G. parviflorum*	Very high	
Buntine	3400			0.0
Bendering	5119	*G. spinosum*, *G. crassifolium*, *G. trilobum*	Low	27.8

Figure 6: a) The regression of all native mammals in wheatbelt reserves (from surveys detailed in Kitchener *et al.* (1980) plus Tutanning NR) against log of reserve area; and b) the regression of residuals from plot of number of mammals versus log area plotted against % *Gastrolobium*.

a)



b)

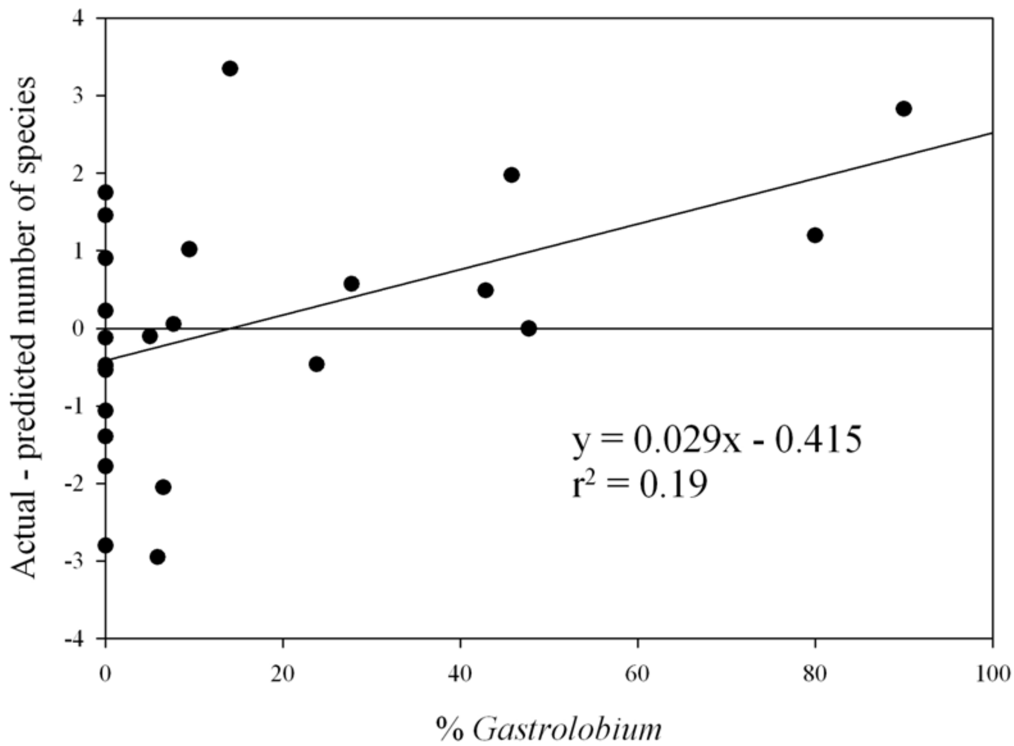


Figure 7: Relative abundance of poison peas *Gastrolobium* spp. in southern Western Australia from survey data collected as part of this project and by the Western Australian Museum in their 1970s survey of wheatbelt reserves. No comparative data is available for the jarrah forest zone to the west of the wheatbelt. Shortridge's rich collecting sites for mammals (the mesic woodland sites) correspond with areas of highest relative abundance. This pattern of relative abundance contrasts sharply with the impression conveyed by a plot of museum records of *Gastrolobium* in the region shown in Figure 3.

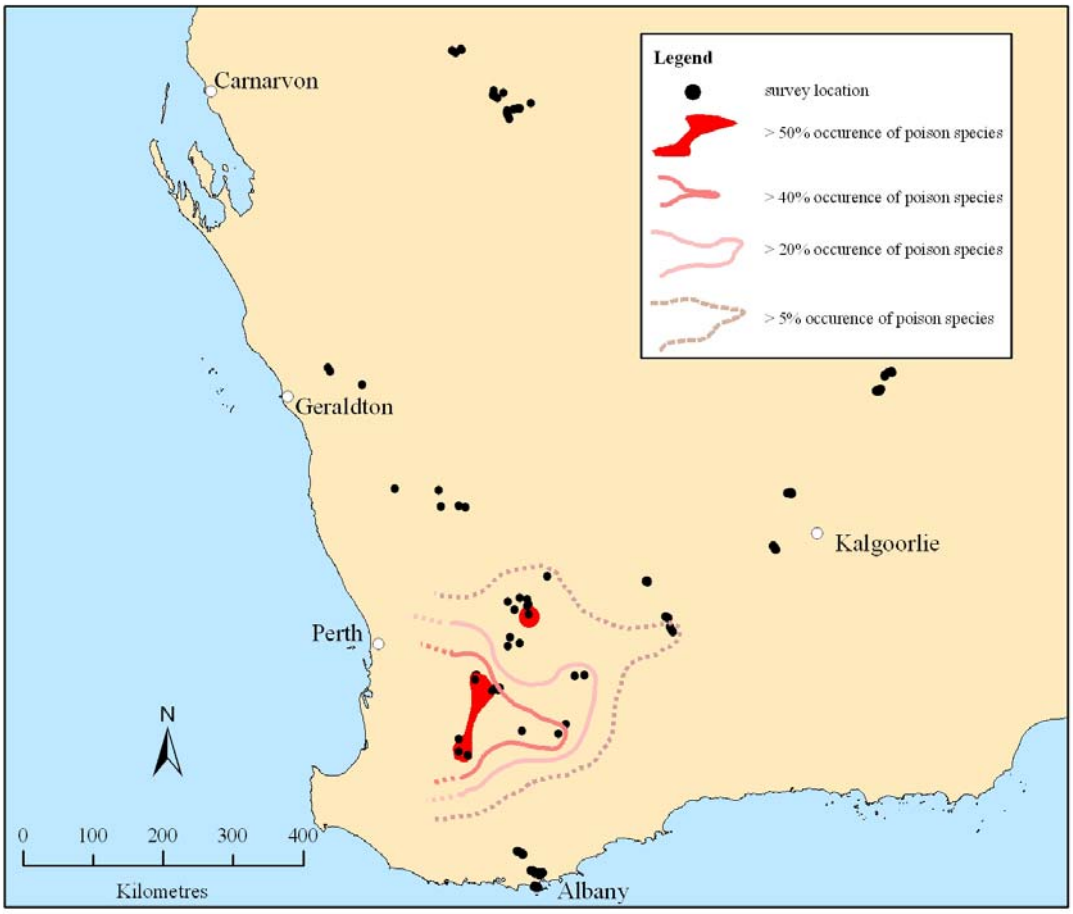


Table 5: Wheatbelt reserves, showing the extent of surrounding land clearing in the 1960s, prior to wildlife surveys in the 1970s. Data are sourced from individual reports on each reserve (e.g. Kitchener 1976, Muir 1977, Muir *et al.* 1978, or from Arnold and Weeldenburg 1991 for Durokoppin and Kodj Kodjin). Values are in hectares (with uncleared land expressed as a percentage of the total surrounding the reserve in a variable area up to *c.* 50 x 50 km^2). Details of how areas calculated are given in individual reserve accounts.

Reserve	Area of reserve	Area of reserve plus surrounding uncleared land 1960 (% of total)	Area of reserve plus surrounding uncleared land mid 1970s (% of total)	% of 1960 land lost to clearing	% of overall area lost to clearing over 10 years
Yoting Water	34	13184 (5.4%)	8960 (3.7%)	32	1.7
Yoting Town	38	13184 (5.4%)	8960 (3.7%)	32	1.7
South Badjaling	41	13184 (5.4%)	8960 (3.7%)	32	1.7
East Yorkrakine	81	9007 (3.3%)	7307 (2.6%)	19	0.7
North Bungulla	104	9007 (3.3%)	7307 (2.6%)	19	0.7
Yorkrakine Rock	158	9007 (3.3%)	7307 (2.6%)	19	0.7
Kodj Kodjin	204	(13%)	(7%*)	46	6.0
Yornaning	247	(8%)	(6%)	25	2.0
Badjaling	272	13184 (5.4%)	8960 (3.7%)	32	1.7
Wilroy	331	41875 (40%)	8375 (8%)	80	32.0
Nugadong Forest	364	45139 (16.9%)	17475 (6.6%)	61	10.3
Nugadong	400	45139 (16.9%)	17475 (6.6%)	61	10.3
Marchagee	577	26382 (25.2%)	17071 (16.3%)	35	8.9
Bindoo Hill	740	18277 (36.1%)	8748 (17.1%)	52	19.0
East Nugadong	772	45139 (16.9%)	17475 (6.6%)	61	10.3
Durokoppin	1030	(13%)	(7%*)	46	6.0
Dongolocking	1061	33450 (12%)	15030 (5.4%)	55	6.6
North Tarin Rock	1415	14600	2300 (?)	84	-
West Bendering	1602	105114 (35.6%)	36634 (12.4%)	65	23.2
Bendering	5119	17400	2300	87	-
East Yuna	1740	20227 (30.3%)	7227 (10.8%)	64	19.5

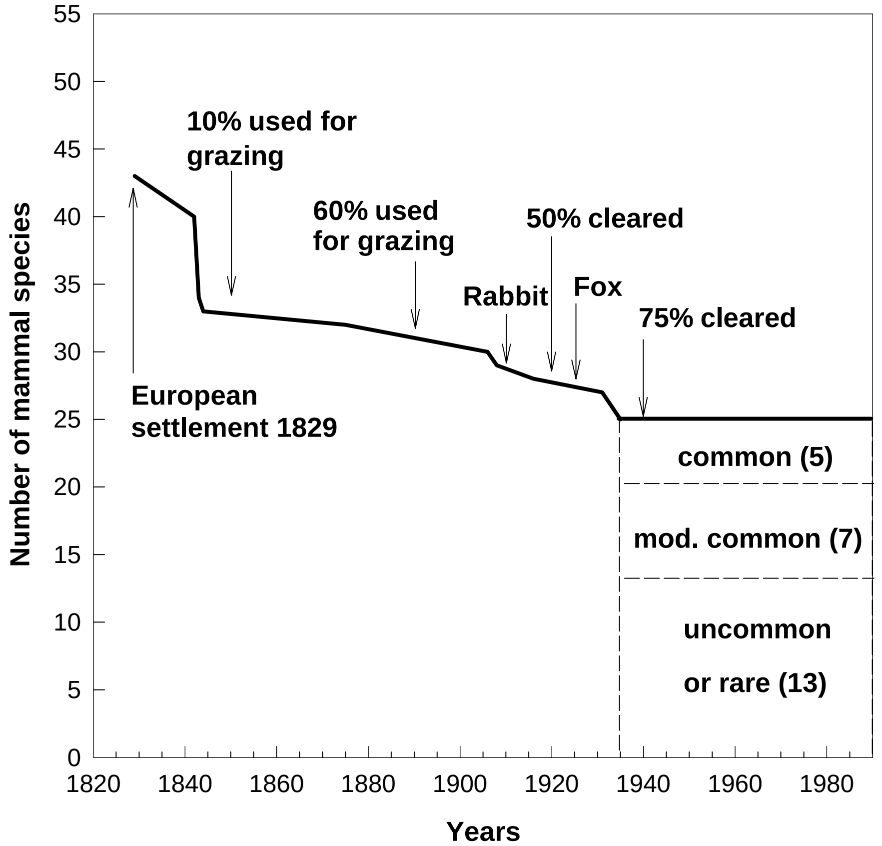
Tarin Rock	2011	14600	2748	81	-
Billyacatting Hill	2075	22930 (11.0%)	13084 (6.2%)	43	4.8
Tutanning	2250	-	-	-	-
Buntine	3400	36656 (15.6%)	17023 (7.3%)	54	8.3

Discussion

Temporal pattern of loss of mammals

The temporal pattern of loss of mammals in the Western Australian wheatbelt is graphed in Figure 8 and juxtaposed against major land use changes or invasions of exotic species. It indicates a rapid loss of fauna from what is now the wheatbelt, well before significant land clearing and before the arrival of European rabbits and foxes. However, a limitation of this data is the paucity of collections of native mammals through much of the nineteenth century. This makes the exact timing of decline difficult to ascertain. Ludwig Preiss collected 24 species of mammal in the south-west in 1838-9 (Glauert 1950) and John Gilbert (the principal collector for John Gould) spent two years and four months in the Swan River Colony commencing in March 1839 (Whittell 1941), together laying the foundation of knowledge on the distribution of the fauna shortly after European settlement in 1829. Assistant Surveyor Austin collected in the southern interior in 1854 and George Masters in the vicinity of King George Sound (at Albany) in the 1860s (Glauert 1950). Their collections suggest that the fauna remained largely intact at this time. The next comprehensive surveys were those of John Tunney in the early 1900s (e.g. Friend and Hall 1991) and Guy Shortridge in 1905-07 (Shortridge 1909, 1936).

Figure 8: The temporal pattern of loss of mammals from the Western Australian wheatbelt (Short 1994). The last museum record for each species is taken from Kitchener *et al.* (1980).



Possible causal factors in mammal decline and extinction – an evaluation

A large number of factors have been identified as possibly contributing to mammal decline in Australia. These factors and key papers discussing each are collated in Table 6. Shortridge is closely associated with the disease explanation for loss of mammals in Australia, but the transcription of his letters indicates that he believed a number of factors were implicated including predation from feral cats. Many of the factors are discussed at length in the published paper (Short in press) and will not be repeated here. In this report we focus on the possible role of feral cats in the demise of the fauna and the role that poison plants and/or vegetation density may have played in ameliorating the impact of predation in some areas.

Table 6: Major factors which may have played a role in the decline and extinction of Australian mammals in historic times.

Factors	Key references
Habitat change	
Stock	Krefft (1866), Marlow (1958), Newsome (1971), Frith (1969), Calaby and Grigg (1989)
Rabbits	Le Souef (1923), Jones (1923-5), Morton (1990)
Fire mosaic	Bolton and Latz (1978), Kitchener *et al.* (1980), Johnson and Roff (1982), Allen (1983), Burbidge (1985), Burbidge and McKenzie (1989), Johnson *et al.* (1989)
Land clearing	Le Souef (1923), Leake (1962), Frith (1973)
Fragmentation	Hobbs *et al.* (1993), Saunders (1994)
Predation	
Foxes	Le Souef (1923), Jones (1923-5), Finlayson (1927, 1958), Kinnear *et al.* (1988)
Cats	Le Souef (1923), Troughton (1938), Dickman *et al.* (1993)
Hunting	Lucas and Le Souef (1909), Le Souef (1923), Roff and Kirkpatrick (1962), Marshall (1966), Lunney and Leary (1988), Short and Smith (1994)
Other	
Climate change	Finlayson (1961), Calaby (1971)
Extended drought	Kerle *et al.* (1992), Braithwaite and Griffiths (1996)
Disease	Shortridge (1909), Le Souef (1923), White (1952), Guiler (1961), How *et al.* (1987), Richards and Short (1996)

Feral cats – a factor in mammal decline in the late nineteenth century?

This exotic species was widely distributed and abundant at the time of Shortridge's surveys ("cats … have run wild in large numbers": Shortridge 1909: 844), likely establishing first in the mesic south-west from the 1850s and the 1870s and 1880s in semi-arid areas (Abbott 2002). Shortridge attributed the absence or decline of specific wildlife species to cats. These included Gilbert's potoroo *Potorous tridactylus gilberti* to the east of Albany (fire was also considered to be a factor), honey possum *Tarsipes rostratus* in southern Western Australia, and western barred bandicoot *Perameles bougainville* on Bernier Island.

Cats were dismissed as a cause of decline by Kitchener *et al*. (1980), largely because of the persistence of mammals on large islands to which cats have been introduced. Burbidge and McKenzie (1989) similarly argued that cats were not a primary factor in the decline of mammals in Western Australia because most species persisted well into the twentieth century long after the establishment of cats.

Abbott (2002) also argued for a limited impact of feral cats on native fauna. His key points were: 1) there has been no demonstrated impact of cats on the Tasmanian fauna despite their presence from earliest European settlement; 2) there has been no demonstrated impact by cats on native fauna following systematic fox control in the 3.5 million hectares of south-west Western Australia since 1996; 3) the spread and impact of feral cats in historic times, particularly in inland Australia, may have been limited by their rapidly becoming a favoured food item of Aboriginal people (perhaps facilitated by widespread drought in the 1880s and 1890s); 4) a lack of time for impact in many areas before foxes arrived; 5) a lack of a "strong signal" in terms of loss of fauna relative to what occurred when foxes colonised (for example the decline of bettongs on the western slopes of New South Wales in the first decade of the 1900s (Short 1998)); and 6) the persistence of some species likely to be vulnerable to cat predation well beyond the time of the supposed arrival of feral cats (such as bandicoots in the 1920s and 1930s in South Australia).

In contrast, Hoy suggested the loss of the larger rodents to predation from cats (Short and Calaby 2001) and Dickman (1996) suggested that the loss of larger native rodents (*Notomys* and *Pseudomys* spp.) and an unnamed potoroid prior to 1857 may have been due to cat predation. Burbidge and Manly (2002) examined the extinction of native mammals on Australian landbridge islands and found that cats were associated with extinctions only on more arid islands, particularly for terrestrial prey, and in the absence of rockpile habitat as shelter for prey species. Overall, they saw the impact of exotic predators, not habitat destruction, as being the major factor driving extinctions of mammals on Australian islands.

Risbey *et al*. (2000) documented an 80% decline in trap success of small mammals (*Pseudomys* spp., *Sminthopsis* sp. and *Mus musculus*) at a semi-arid site where control of foxes allowed cat numbers to increase. In addition, evidence from reintroductions of a range of threatened mammals highlight the importance of predation by feral cats in arid and semi-arid areas (Christensen and Burrows 1994; Gibson *et al*. 1994; Short and Turner 2000; Richards and Short 2003; Priddel and Wheeler 2004).

The possible role of Gastrolobium

Poison peas (*Gastrolobium* spp.) are widely distributed throughout the south-west of Western Australia (Figure 3), including agricultural and forested areas. They are typically associated with hard-setting loamy soils and shallower gravely and sandy soils, but do not occur on alkaline soils, boulder laterite or on deep sands (Aplin 1971). Losses of stock from eating the plants have been reported from the time of first European settlement (1837: Meadly in Gardner 1937) and were still reported in relatively recent times (Aplin 1971). They put a brake on land clearing by early settlers, with some areas left uncleared eventually becoming national parks and nature reserves (Hopper 1991). Examples include Tutanning Nature Reserve, Stirling Range National Park and Mt Lesueur National Park.

The toxic property of *Gastrolobium* was identified as monofluoroacetic acid (fluoroacetate) in 1964 (Aplin 1971). This substance (typically known as '1080') has been used extensively as a poison for vertebrate pests, particularly for the control of rabbits in Australia. The amount of fluoroacetate varies widely between species of *Gastrolobium*, varying from 2650 ppm for Heart-leafed Poison to < 100 ppm for some species (Aplin *et al.* 1983). Toxin levels are generally highest in parts of the plant in active growth such as flowers.

Tolerance levels of native and exotic species are well known from detailed studies in eastern and Western Australia (e.g. McIlroy 1981, 1985, Twigg and King 1991). Domestic and introduced mammals have a very low tolerance to fluoroacetate. Native species occurring in south-west Western Australia typically have a high tolerance to the toxin. Mead *et al.* (1985) described a "co-evolutionary arms race" between *Gastrolobium* spp and the animals of south-western Australia. Species such as western grey kangaroos were able to regulate their intake, eating large amounts of species low in fluoroacetate (*G. spinosum*; Plate 6) and smaller amounts of species high in fluoroacetate (*G. bilobum*).

Plate 6: *Gastrobium floribundum* at Southern Cross.

Secondary poisoning of carnivores can potentially occur if they eat carrion of herbivores poisoned by eating '1080' (McIlroy and Gifford 1992) or animals that have fed on *Gastrolobium* (Christensen 1980, Peacock *et al.* 2002). Cats, dogs and foxes were considered potentially at risk from rabbit poisoning campaigns using '1080'-treated carrot. Foxes were the species found dead most frequently after 22 rabbit poisoning campaigns (McIlroy 1982). The incidence of finding cat carcases after such campaigns was much lower, but this may reflect their lower abundance relative to foxes. Similarly, radio-collared foxes died after eating rabbits that had fed on '1080'-poisoned oats at Watheroo National Park in Western Australia (King and Kinnear 1991). Secondary poisoning has been also reported of dogs and cats eating native bronzewing pigeons that have fed on *Gastrolobium* (Mann 1906, Peacock *et al.* 2002, Peacock *et al.* 2004). Serventy (1966) reported that the entrails of the burrowing bettong *Bettongia lesueur* were poisonous to dogs in south-west Western Australia and linked this to its tendency to feed on seeds of poison plants, in a similar manner to bronzewing pigeons. Christensen (1980) reported "introduced predators such as the fox may suffer secondary poisoning after eating native animals that have fed on the leaves, seeds or flowers of these plants (Plate 7). On record is the case of a farmer who lost his pigs after feeding them woylies [a native rat-kangaroo] accidentally trapped in rabbit traps."

Plate 7: The European red fox. Photo © Jiri Lochman, Lochman Transparencies.

It is unclear whether all species of *Gastrolobium* will result in secondary poisoning of carnivores or only the most toxic species. Herbert (1921) reported dogs and cats dying from eating the entrails or bones of pigeons and possums that had eaten poison plants, but only when these species fed on Box Poison, not York Road Poison. Box Poison is reported to have up to 2500 ppm of toxin, York Road Poison *c.* 400 ppm (Aplin 1971, Aplin *et al.* 1983).

The use of '1080' poison for rabbit control was widespread in the wheatbelt prior to 1970. However, the introduction of the European rabbit flea in 1969 greatly improved the effectiveness of myxomatosis as a method of control for rabbits and resulted in a major reduction in the use of poison (Christensen 1980, King *et al.* 1981). An unintended consequence of this was that fox populations increased due to the lack of secondary poisoning from eating poisoned rabbits (King *et al.* 1981). This is believed to have led to the collapse of mammals at Perup Nature Reserve (Christensen 1980), Tutanning Nature Reserve (G. Friend 1990) and at Dryandra Forest (J. Friend 1990). Remaining patches of remnant bushland in the wheatbelt were probably too small to confer adequate protection against incursions of foxes, despite the presence of *Gastrolobium*. J. Friend (1990) suggested that numbats required large areas beyond 3 km from the forest-farm interface to persist, however foxes are most active in such areas.

The presence of *Gastrolobium* in understorey vegetation (often as thickets) has been specifically acknowledged as contributing to the conservation of specific species of mammal in south-west Western Australia. These include the red-tailed phascogale *Phascogale calura* (Kitchener *et al.* 1976), tammar wallaby *Macropus eugenii* (Christensen 1980), numbat (J. Friend 1990), and brush-tailed bettong *Bettongia penicillata* (Courtenay 1994, Mitchell and Higgs 1994, Start *et al.* 1996). However, this contribution will have diminished as land clearing has further reduced the amount of remnant vegetation in the vicinity of key reserves. Reserves that have conserved native mammals have abundant *Gastrolobium* spp: Dryandra: Sandplain Poison *G. microcarpum* (Plate 8); Boyagin NR: *G. parviflorum*; and Perup: *G. bilobum* (Calaby 1960, Friend 1990, Friend and Thomas 1994, Christensen 1980a, b)).

Plate 8: Sandplain poison *Gastrolobium microcarpum* and wandoo (*Eucalytus wandoo*) woodland. Photo © Marie Lochman, Lochman Transparencies.

Role of dense vegetation

The importance of dense vegetation to the persistence of mammals was highlighted by Christensen (1980). This importance of dense vegetation in ameliorating the impact of predation provides an explanation for the persistence of some species only in the more mesic parts of their range in south-west Western Australia. Quokkas *Setonix brachyurus* now only persist on the mainland "within the protection of dense vegetation in swamps, along creeklines and in gullies" (Short *et al.* 1992; Sinclair and Morris 1995-6). They have persisted on Rottnest Island in the presence of cats, probably due to the shelter provided by dense vegetation of the lily *Acanthocarpus preissii* and other species. Similarly, feral cats and tammar wallabies *Macropus eugenii* have co-existed on Garden Island (Kinnear *et al.* 1990) in the presence of dense understorey vegetation. Similarly, southern brown bandicoots *Isoodon obesulus* persist on the mesic Swan Coastal Plain in dense vegetation (Gardner 2004), but not in the wheatbelt where vegetation is sparser.

Management implications

A greater knowledge of the role secondary poisoning (resulting from the presence of abundant and toxic species of *Gastrolobium* in the landscape) may play in limiting the distribution, abundance, and impact of feral cats (and European foxes) may provide useful management insights and spin-offs for the improved conservation of native mammals. Examples might be:

Facilitate improved predator management at fauna recovery sites

1. Greater emphasis on the management of feral cats to ensure persistence of vulnerable native mammal populations, given their likely role in the extinction of many native mammal species. The likely importance of this species in faunal decline has been unrecognised until comparatively recently.
2. The greater use of understorey plantings of *Gastrolobium* as a buffer around key fauna recovery sites may promote faunal recoveries.
3. Providing *Gastrolobium* seed as a feed supplement to free-range native species that have a high tolerance may create living 'toxic wildlife' that results in the death of invading exotic predators. This strategy might be particularly important for the management of reintroduced populations of species known to be highly sensitive to cat predation. The management of feral cats has proved particularly

difficult at some reintroduction sites using conventional methods, resulting in the death of reintroduced stock. This might provide a solution.

Identify new opportunities to re-establish mammal fauna

4. Knowledge of the 'toxic load' of a landscape due to *Gastrolobium* may be important in identifying new areas for re-establishment of mammal species, where the management of exotic predators is aided by the presence of *Gastrolobium* and the consequent secondary poisoning.

Conservation of Gastrolobium

5. *Gastrolobium* species differ widely in toxicity to stock and this information could be used to encourage a more selective removal of only the most toxic species from farms. Note that several species of *Gastrolobium* are declared rare flora within Western Australia.

Landscape management for conservation

6. The possibility of buying back farming properties (or part-properties) adjoining key reserves and restoring vegetation, including a major understorey of *Gastrolobium*, should be investigated for feasibility.
7. Greater emphasis should be placed on the inclusion of *Gastrolobium* in replanting for salinity control and habitat reconstruction. This might apply particularly to non-farmer groups involved in replanting (Main Roads Department, community groups such as the Malleefowl Preservation Group and Men of the Trees, and groups such as Gondwana Link seeking to construct macro-corridors across the landscape between key reserves in the southern wheatbelt).
8. Re-evaluation of the current policy of fire suppression in wheatbelt nature reserves, given the apparent link between fire and regeneration of thickets of *Gastrolobium* (for example, Heart-leafed Poison requires infrequent hot fires to regenerate: Christensen 1980b; Friend *et al.* 1994).

In a similar way, recognition of the importance of dense cover in ameliorating predation suggests:

9. Greater care is needed in the opening up of remaining areas of dense bushland on the coastal fringes (by construction of roads or tracks, by excessive fire, or by

further clearing), which may threaten remnant populations of native mammals by allowing incursions by exotic predators.

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Appendix 2: Isolated wheatbelt reserves sampled as part of the Western Australian Museum surveys of the 1970s showing area of reserves (ha), number of mammal species (all mammals, critical weight range (CWR) species, or arboreal only), the percentage of sample sites in each reserve with *Gastrolobium* recorded, vegetation density in three strata (canopy, mid-storey, and understorey), area of woodland or heath/shrub/mallee habitat type within the reserve, and the diversity of the two major habitat types (as measured by the Shannon-Wiener Index). Data are collated from individual publications on each reserve (e.g. Kitchener 1976, Muir 1977, and Muir *et al.* 1978).

Reserve	Area	CWR mammals	All natives	Arboreal CWR	% poison	Mean rainfall	%dense canopy	%dense mid/st	%dense under/st	Area wood	Area of h/s/m	SWI
Yoting Water	34	0	1	0	0.0	381	18.2	0.0	0.0	29	5	0.602
Yoting Town	38	0	1	0	7.7	381	0.0	23.1	38.5	11	25	0.888
South Badjaling	41	0	0	0	0.0	381	0.0	37.5	0.0	34	7	0.659
East Yorkrakine	81	1	2	0	5.0	332	5.0	20.0	10.0	1	80	0.096
North Bungulla	104	1	2	0	0.0	332	0.0	48.6	29.7	1	99	0.046
Yorkrakine Rock	158	1	3	0	0.0	332	14.8	18.5	0.0	87	28	0.801
Kodj Kodjin	204	1	4	0	42.9	339	0.0	21.4	3.6	103	100	1.000
Yornaning	247	3	5	2	80.0	420	52.0	8.0	28.0	158	74	0.903
Badjaling	272	0	1	0	5.9	381	0.0	17.6	11.8	87	154	0.944
Wilroy	331	1	6	0	0.0	326	0.0	45.7	5.7	17	315	0.291
Nugadong Forest	364	2		0	0.0	362	0.0	46.8	0.0	123	148	0.994
Nugadong	400	2	4	0	0.0	362	0.0	43.8	6.3	80	320	0.722
Marchagee	577	1	6	0	0.0	397	0.0	12.5	40.0	1	194	0.026
Bindoo Hill	740	1	5	0	0.0	341	0.0	68.1	19.1	1	480	0.012
East Nugadong	772	2	7	0	0.0	362	0.0	30.2	26.4	1	772	0.008
Durokoppin	1030	2	7	1	9.5	339	8.1	45.9	23.0	326	697	0.903
Dongolocking	1061	3	8	3	45.8	381	15.9	10.3	24.3	640	411	0.965
North Tarin Rock	1415	3	6	0	23.8	359	9.5	35.7	2.4	14	688	0.141
West Bendering	1602	4	10	2	14.1	338	7.8	35.9	14.1	316	991	0.798
East Yuna	1740	1	5	0	0.0	341	0.0	23.8	9.5	5	1580	0.031
Tarin Rock	2011	4	5	2	47.7	359	9.1	27.3	31.8	158	2235	0.351

Billyacatting Hill	2075	1	4	0	6.5	308	2.2	28.3	13.0	162	543	0.778
Tutanning	2250	7	10	4	90.0	420	20.7	3.5	13.8	2186	64	0.324
Buntine	3400	2	5	0	0.0	362	0.0	46.8	15.1	179	2846	0.324
Bendering	5119	5	9	2	27.8	338	5.3	40.3	39.2	154	4761	0.201