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Non-volant mammals of the southern Carnarvon Basin, Western Australia

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Abstract – We sampled non-volant mammals on 63 quadrats chosen to represent the geographical extent and diversity of terrestrial environments in the 75 000 km² Carnarvon Basin study area.

One monotreme, three macropod, one honey possum, ten dasyurid, four rodent and nine introduced species were recorded extant on the quadrats. Analysis revealed that patterns in the species composition of the small indigenous mammal assemblages were related to gradients in climate and soil texture.

The original mammal fauna of the study area was reconstructed from available sub-fossil, historic and contemporary records. Twenty-three of the original 48 indigenous species are now extinct there, a decline that commenced well before the advent of foxes.

INTRODUCTION

This paper is the first systematic review of the entire non-volant mammal fauna of the southern Carnarvon Basin (Figure 1), which corresponds almost exactly to the western half of Shortridge's 'Central district' (Shortridge, 1910).

Virtually all the mammal records from the study area prior to 1900 AD are from the Shark Bay islands and Peron Peninsula. These are reviewed in Ride *et al.* (1962). The earliest island records were made in 1699 by William Dampier of HMS Roebuck, whereas the first mainland records were collected on Peron Peninsula in 1801 by the scientists and crew of the *Geographe*. The only historical information from inland parts of the study area comprises geographically vague observations of medium to large mammals encountered by early pastoral explorers, and a scatter of more modern records associated with specimens sent to the Western Australian Museum. Until the surveys of Bernier and Dorre Islands (Ride *et al.*, 1962), Kalbarri National Park (Bannister, unpublished), Dirk Hartog Island (Burbidge and George, 1978), and Heirrison Prong (Short *et al.*, 1992), available historical records were biased towards species with a body weight exceeding 50 grams.

A pastoral industry has operated in the study area since before 1880 (Friedel and James, 1995; Payne *et al.*, 1987; Beard, 1976). During the same period, foxes, rabbits and a variety of other exotic mammals colonised the study area. The initially high stocking and turn-off rates of sheep and cattle have declined until most pastoral leases can sustain less than 50% of their original capacity. During the last decade this has led to a de-facto reliance on feral goats to generate income.

As early as 1910, natural historians noted extinctions in the region's indigenous mammal fauna: "*... their disappearance, which is said to have been first noticed about 1880, being most sudden and unaccountable*" (Shortridge, 1910, p. 818). But the lack of systematic surveys of extant mammals has precluded any investigation of changes in the status of indigenous mammals across the study area that is more explicit than the state-wide review by Burbidge and McKenzie (1989), and more extensive than the reviews of sites in Shark Bay area (e.g. Baynes, 1990).

Our aim was to provide a regional context for conserving the study area's terrestrial, non-volant, mammal fauna. Four specific goals were defined:

- carry out the first systematic field survey of the terrestrial mammals that are extant in the study area,
- lodge voucher collections in the Western Australian Museum for detailed taxonomic appraisal in the future,
- integrate our field survey data with existing historical records, and with the late-Holocene sub-fossil records (Baynes, 1990, and Appendix 2), to provide an overview of the status and distribution of mammal species in the study area and a perspective on recent changes in their composition and geographic patterns, and
- identify attributes of the physical environment that provide predictors of gradients in species composition across the study area.

METHODS

Study Area

The Carnarvon Basin study area covers 75 000 km² on Australia's western coast. It is centred on

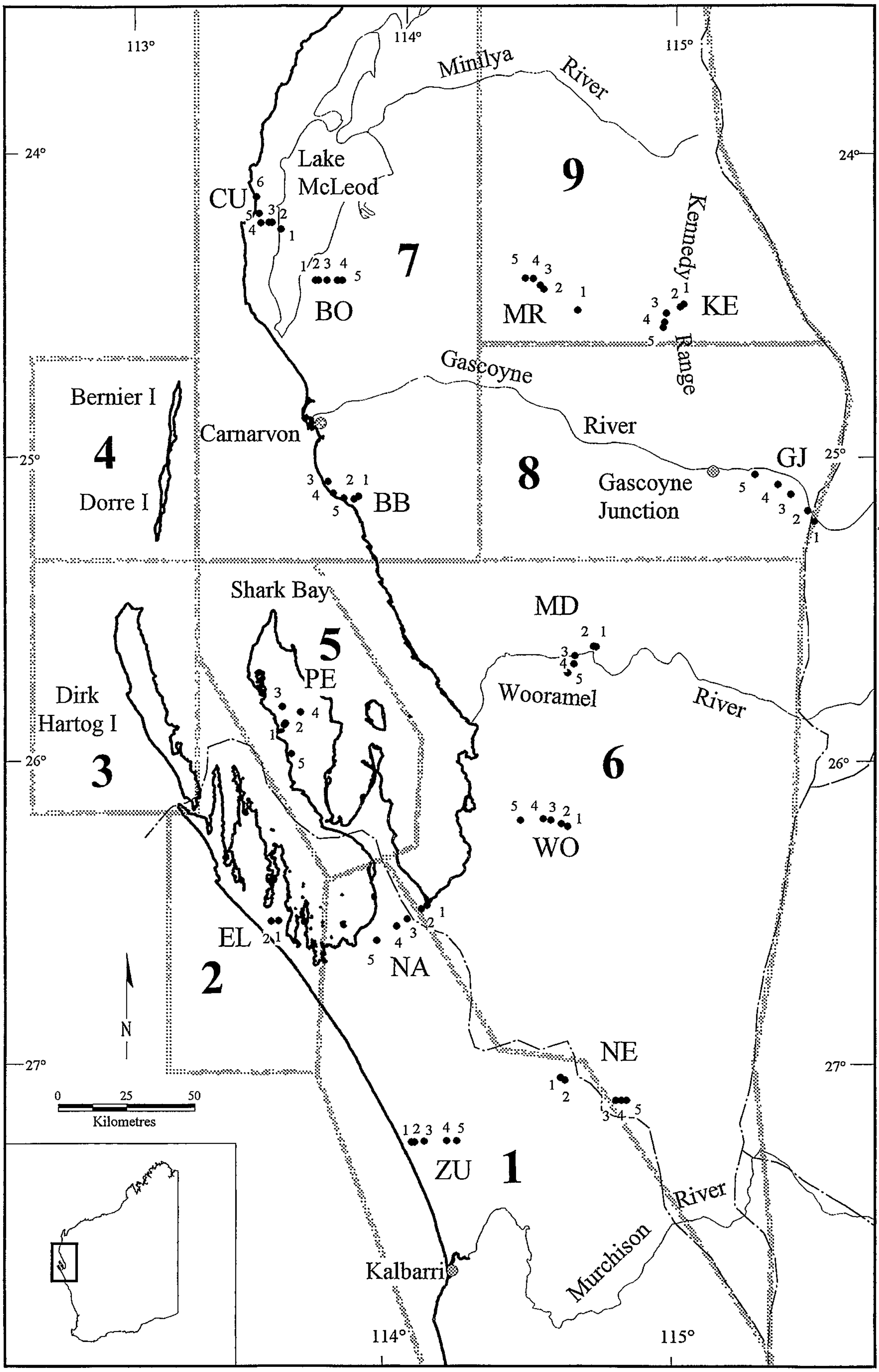


Figure 1 The Carnarvon Basin study area, showing the nine sectors used for faunal reconstruction (half tones) and the quadrats associated with each survey area. Survey area codes are as follows: BB (Bush Bay), BO (Boolathanna), CU (Cape Cuvier), EL (Edel Land), GJ (Gascoyne Junction), KE (Kennedy Range), MD (Meedo), MR (Mardathuna), NA (Nanga), NE (Nerren Nerren), PE (Peron), WO (Woodleigh) and ZU (Zuytdorp).

Plate 1 *Zyzomys argurus*, photographed in the Kennedy Range by Jiri Lochman in 1995.

Shark Bay, and extends northwards from 28°S (the Murchison River) to 23°30'S (the Minilya River), and eastwards to beyond Gascoyne Junction (Figure 1).

Its physical environments are detailed by Wyrwoll, Stoneman, Elliott and Sandercock (2000) and Wyrwoll, Courtney and Sandercock (2000). Briefly, the region is a lowland characterised by gentle gradients on a basement of soft sediments. Under a variety of climates, interacting alluvial and aeolian processes have produced a complex landscape mosaic, that has been further modified by extensive coastal transgressions associated with sea-level changes. Today, the area south of Shark Bay has a semi-arid climate influenced by temperate weather systems (mainly winter rainfall). From Shark Bay northward, the climate is influenced by both tropical and temperate systems; semi-arid at the coast, but arid with locally unreliable summer and winter rainfall further inland. In phytogeographical terms, the study area comprises the northern half of the Irwin District of the South-western Province, as well as the southern half of the Carnarvon District of the Eremean Province (Beard, 1980).

Extensive alluvial plains dominate the study area, although erosional uplands such as the Kennedy Range occur in its eastern parts. The plains are traversed from east to west by two large, ephemeral rivers lined with groves of River Gum (*Eucalyptus victrix*): the Gascoyne and Wooramel. Low open woodlands of bowgada (*Acacia linophylla*) and snakewood (*A. xiphophylla*) over *Atriplex, Senna* and *Eremophila* shrubs and tussock grasses cover the plains, with *Acacia grasbyi* in areas where calcretes are exposed. Low red sand ridges scattered across the plains support shrubs over mainly hummock-grasses. In northern parts, the plains grade into red sand dune fields that support hummock-grass and mulga (*A. aneura*) communities reminiscent of the red centre. In the south the plains support woodlands of *Eucalyptus loxophleba* and *Callitris glaucophylla*, with mallee, *Banksia, Allocasuarina* and *Actinostrobus* scrubs and heaths on greyish and yellow sand dunes. A strip of limestone that follows the coast southwards from Shark Bay is partially mantled by pale yellow to grey sands supporting low proteaceous heaths with emergent thickets of *Banksia* and mallees such as *Eucalyptus illyarrie*. White coastal sand dunes support *Spinifex longifolius* communities. Low-lying saline areas, such as the fringes of Lake MacLeod and the coastal flats of Shark Bay, support samphire and saltbush communities. Detailed descriptions of

Table 1 Quadrats that had not yielded any rodent (R), any dasyurid (D) or any small ground mammal (N) species at all during the Spring 1994 and May 1995 sampling. Campsite names and locations are provided in Figure 1.

Campsite	Quadrat 1	2	3	4	5	6
BB	–	N	–	D	D	
BO	–	–	D	D	D	
CU	–	–	–	–	–	D
EL	–	–				
GJ	–	D	D	–	D	
KE	–	–	–	–	D	
MD	D	N	D	N	R	
MR	–	–	R	–	–	
NA	–	–	R	–	R	
NE	–	–	–	–	–	
PE	–	–	–	–	–	
WO	R	–	D	R	–	
ZU	–	–	–	R	–	

Table 2 Total number of 'fenced pitfall-trap array' nights per quadrat during the March 1996 trapping session and over the entire survey programme. Campsite names and locations are provided in Figure 1.

Campsite	Table 2a. MARCH 1996 Quadrat 1	2	3	4	5	6	Table 2b. ENTIRE SURVEY Quadrat 1	2	3	4	5	6
BB	4	14	4	14	8		24	38	24	34	28	
BO	6	6	24	32	24		26	26	44	52	44	
CU	3	3	3	4	8	8	23	23	23	24	28	28
EL	0	0					18	18				
GJ	8	8	9	4	4		28	32	33	24	28	
KE	4	4	8	4	8		24	28	32	28	32	
MD	8	8	7	18	8		32	32	31	32	32	
MR	6	4	8	4	8		26	24	32	24	28	
NA	8	8	12	4	10		32	28	36	24	34	
NE	4	4	4	4	4		24	24	24	24	24	
PE	3	10	8	8	8		23	34	28	28	32	
WO	9	6	6	6	6		33	26	30	30	26	
ZU	3	4	4	4	4		23	24	24	28	24	

the vegetation in the study area are provided by Beard (1975, 1976), Payne *et al.* (1987) and Keighery *et al.* (2000).

Field Sampling

Non-volant mammals were sampled on 63 quadrats (2 to 6 quadrats clustered around each of 13 survey areas, herein referred to as campsites). Sampling was sparse. The Carnarvon Basin study area encompassed 7.5 million hectares, and a total of 1008 hectares was actually sampled (each quadrat was 400 x 400m = 16 hectares, and 63 quadrats x 16 ha = 1008 ha). Thus, only 0.013% of the study area was actually sampled.

Quadrats were positioned throughout the geographical extent of the study area. They were placed in typical examples of each of the surface stratigraphic units that characterise the study area. Many quadrats were pseudo-replicated (locally as well as at distant points) to allow for the internal heterogeneity of the stratification units (hypothesised scalars) and to minimise any analytical circularity introduced by the stratification (see McKenzie *et al.*, 1991a).

Table 3 Small ground mammal captures in bucket (B) and tubular (T) pit-traps during each sampling session, and total number of individual pit-trap-nights of effort per sampling session.

	Oct 94 B	Oct 94 T	Jan 95 B[1]	Jan 95 T[1]	May 95 B	May 95 T	Nov 95 T[1]	Mar 96 T
Tarsipes rostratus	3	14	–	–	3	6	–	2
Notomys alexis	2	41	–	–	–	19	22	38
Pseudomys albocinereus	4	24	2	21	6	33	3	5
P. hermannsburgensis	6	31	–	2	6	50	11	12
Mus musculus	3	7	–	–	2	13	4	9
Dasycercus cristicauda	–	1	–	–	–	–	–	–
Dasykaluta rosamondae	–	1	–	–	–	1	–	1
Antechinomys laniger	–	–	–	–	–	–	1	–
Sminthopsis hirtipes	–	4	–	–	1	3	5	7
S. youngsoni	2	10	–	–	1	12	1	4
S. longicaudata	–	2	–	–	1	7	2	1
S. macroura	–	10	–	–	4	8	1	7
S. dolichura	4	20	–	7	3	25	3	6
S. crassicaudata	–	9	–	–	2	6	–	2
S. granulipes	1	4	–	–	1	3	–	–
Pit-trap nights[2]	1220	3660	12	72	1244	3704	516	2736
Total specimens	25	178	2	30	30	186	53	94
Trap return %[3]	2.0	4.9			2.4	5.0		3.4

[1] only a sub-set of sites were trapped
[2] Total bucket trap-nights = 2476; total tube trap-nights = 10 688.
[3] Specimens/100 trapnights.

Trapping and searching were used to detect species' presence-absence on quadrats. Two fenced pit-fall trap arrays were set up on each quadrat. The arrays each comprised a line of six PVC tubular pit-traps, 125 mm in diameter and 500 mm deep, spaced at 10 m intervals along a 50 m flywire drift fence that was 300 mm high. About five m from either side of the 50 m fence was a bucket pit-trap 300 mm in diameter and 450 mm deep positioned at the centre of a 10 m long drift fence. Herein, an array is referred to as a 'drift-fence'.

The quadrats were sampled for five days and nights in spring 1994 (27 September–20 October) and in autumn 1995 (9 May–8 June), a total of 10 drift fence nights per quadrat per seasonal visit. The two quadrats on Edel Land (EL) were first sampled in January 1995 (for 3–4 nights), then re-sampled for five nights during the Autumn 1995 fieldwork.

Data Quality

Species accumulation curves were used to assess the results of the trapping programme. A curve was plotted for each of the 13 survey areas (= campsites) showing the increase in 'new quadrat species-records' per day during the course of the trapping programme. Thus, the first record of *Sminthopsis dolichura* at NA3 was treated as a new record (quadrat-species intersection) in the NA accumulation curve even if it had previously been recorded at other NA quadrats.

A sub-set of the quadrats were re-sampled in November 1995 to ground-test the robustness of the sampling. We re-sampled 23 of the 63 quadrats for two nights each (BB2, GJ2, GJ3, GJ5, KE2-5, MD1-5, MR3, NA1, NA3, NA5, PE2, PE5, WO1, WO3, WO4, ZU4). This sub-set included 17 of the 23 quadrats where there appeared to be 'gaps' in the expected community structure, i.e. no dasyurid and/or no rodent species had been detected (Table 1).

- If the only new mammals from the quadrats were our hypothesised 'gaps', then we would treat the sampling as otherwise robust.
- If, on average, <10% of the 'total small ground-dwelling mammal species' (tsgms) recorded were new non-'gap' species, we would assume that the sampling was robust enough, unless some consistent pattern emerged.
- If, on average, >10%, of the 'tsgms' recorded were new non-'gap' species, then we would re-sample all quadrats in March 1996.

Further sampling was carried out at all quadrats (except for the two on Edel Land) in March 1996 (Table 2a), with particular emphasis on those that had still yielded few if any small ground mammals. The total number of drift-fence-nights completed at each quadrat over the entire sampling programme is provided in Table 2b, and the overall trapping effort by trap-type is listed in Table 3. In addition, small numbers of mammals were captured in the lines of five invertebrate buckets that were continuously open for 12 months on each quadrat, even though these buckets were all lidded by sheets of wire mesh (10 mm square holes) designed to prevent accidental mammal deaths.

Because of inconsistencies in effort, and the addition of conical baffles to the pit-traps, 'quadrat-records' added by the November 1995 and March 1996 trapping sessions are plotted as a single point (day 11) on the species accumulation curves, as are records derived solely from the invertebrate pits (as day 12).

Historical Review

Lists of the non-volant mammals previously captured in the study area were extracted from existing literature and the Western Australian Museum's zoological register. We treat *Canis lupus dingo* as indigenous, but *Felis catus* and *Mus musculus* as introduced species, although both species probably pre-date European settlement (Burbidge *et al.*, 1988).

The original fauna of the study area was re-constructed by adding the results of our field sampling programme and the Late Holocene sub-fossil mammal records (Appendix 2) to these historical data. Species records were assigned among nine geographic sectors, distinguished in terms of phytogeographic boundaries, distance inland, distance from the coast, and latitude (see Figure 1). This considerable loss of spatial resolution was necessary because the localities of the historical records and the sub-fossil sites were unrelated, and scattered across the study area in patterns that were independent of the stratification used to position the 63 quadrats on which our field surveys of non-volant mammals focussed.

Analysis

The assemblages of small, indigenous, ground-

Table 4 Number of small ground mammal species recorded during the November 1995 sampling session/number of species that were new records for the quadrat. Campsite names and locations are provided in Figure 1.

Campsite	Quadrat 1	2	3	4	5
BB	–	1/0	–	–	–
GJ	–	1/0	0/0	–	1/1
KE	–	1/0	2/0	2/1	0/0
MD	2/1	3/3	1/1	0/0	1/1
MR	–	–	1/0	–	–
NA	2/1	–	3/1	–	3/1
PE	–	3/1	–	–	3/0
WO	1/0	–	0/0	0/0	–
ZU	–	–	–	3/2	–

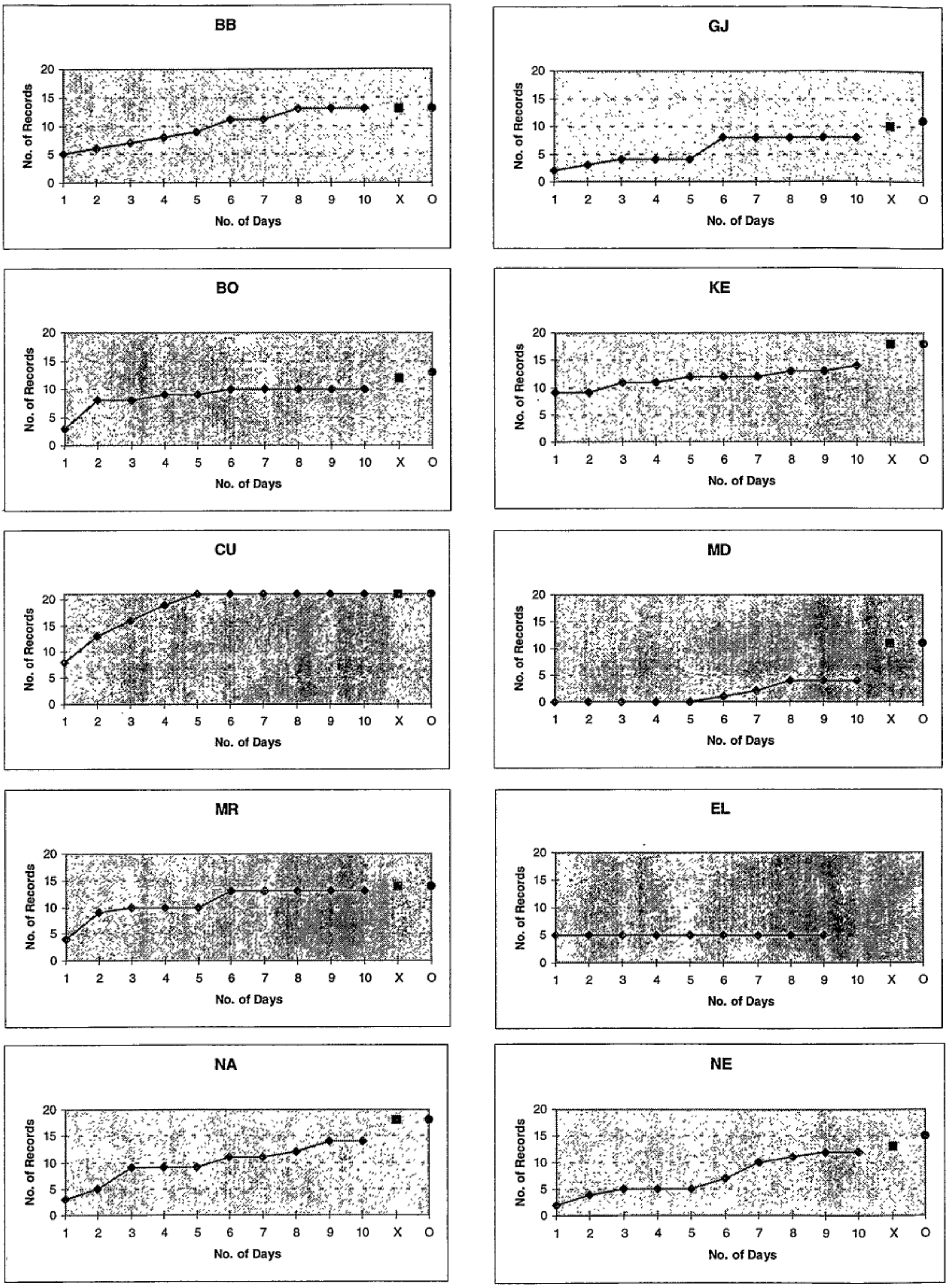
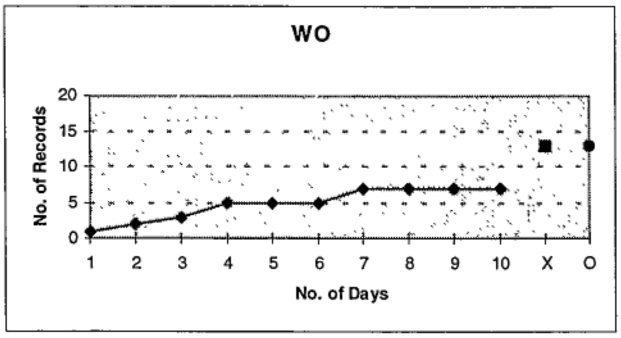
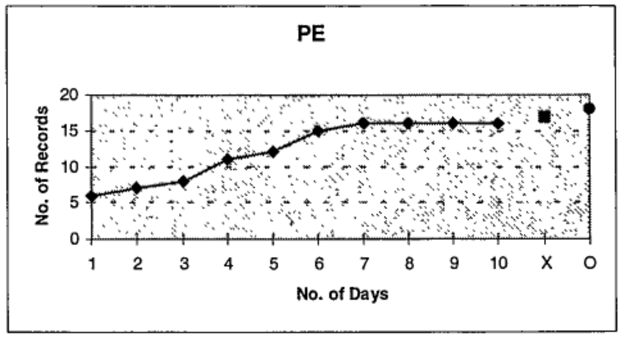


Figure 2 Accumulation of 'records' (quadrat-species intersections — defined in text) of small ground-dwelling mammals during the course of the trapping programme. The day-point labelled 'X' is the summed improvement from the trapping carried out in November 1995 and March 1996. The day-point labelled 'O' indicates extra records contributed by the invertebrate pitfall traps.





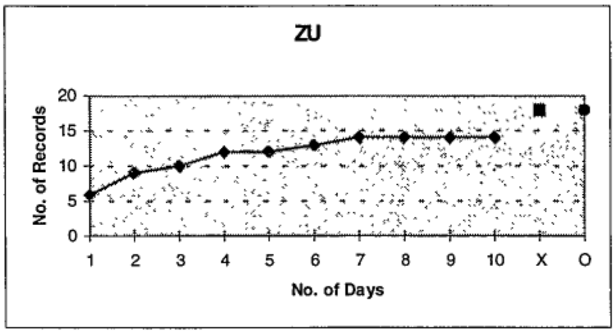


Figure 2 (cont.)

dwelling mammals trapped on the quadrats were used as the input data for analyses of patterns in the extant fauna. We analysed the presence and absence of species, rather than their relative abundance, because limitations in sampling techniques, aggravated by staff and time limitations, precluded reliable abundance estimates (Austin, 1984; McKenzie *et al.*, 1991a).

The analysis package PATN (Belbin, 1995) was used to seek patterns of species composition in the mammal data matrices. The clustering techniques selected were described in McKenzie *et al.* (1991b). Briefly, the association measure 'Two-step' (Belbin, 1980) was used to determine the quantitative relationship between each pair of species, and the Czekanowski measure (Czekanowski, 1932) was used to compare the quadrats according to their species similarities. For both measures of association, a modified version of 'unweighted pair group arithmetic averaging' (UPGMA – Sneath and Sokal, 1973; Belbin, 1995) hierarchial clustering strategy was used, with the clustering parameter (Beta) set to -0.1. To test the robustness of the clusters, and reveal gradients in composition, species were ordinated in 3-dimensional space using Semi-strong Hybrid scaling (Belbin, 1991), then a Minimum Spanning Tree was superimposed.

The biological patterns revealed by these analyses were investigated in terms of a set of attributes related to the physical environment of the quadrats, and to the known habitat preferences of the species throughout their ranges elsewhere in Australia.

The climatic attributes of each quadrat were estimated using ANUCLIM (McMahon *et al.*, 1995). Their soil and geomorphic attributes were provided by Wyrwoll, Stoneman, Elliott and Sandercock 2000). Significant inter-correlations between quantitative attributes were identified using Rank Correlation (Kendall's tau), and are listed in the Appendix I.

Geographical and co-occurrence patterns in the species composition of the re-constructed Late Holocene mammal fauna were also analysed using the Czekanowski measure (see above), although lack of spatial resolution precluded any quantitative analysis of the re-constructed fauna in relation to soil and landform attributes. Macropods were excluded from this analysis because small macropods are inconsistently represented in sub-fossil deposits (Baynes, 1990, p. 323), and there are no historical accounts of their presence or absence in some sectors. Sector-4, comprising the two off-shore islands, was also excluded from the analysis to avoid variation caused by the extirpation effects associated with relatively small insular populations.

Average climatic values were calculated for each of the geographic sectors (Figure 1). They were derived from the ANUCLIM attributes of points distributed at 10 to 15 kilometre intervals across the areal extent of each sector.

RESULTS

Field Sampling

The species accumulation curves (of new quadrat records from each camp per day: Figure 2) appear to approach an asymptote by day 10, the end of the Spring 1994 to Autumn 1995 trapping programmes.

Table 5 Species recorded alive in the study area during the period of European settlement, but not captured during our field survey. Note that we did not sample Kalbarri or the Shark Bay islands.

Species	Locality	Last Record	Notes[1]
Macropus eugenii	Kalbarri	1979	WAM18222, male adult road kill, 19 Apr 1979; WAM27204, skin, no date.
Bettongia lesueur	Dirk Hartog I	1858	Collected during voyage of HMS Herald. BM (Thomas 1888). Earlier, many skulls were collected under an 'Osprey' nest during the 1803 voyage of Uranie (Quoy and Gaimard, 1824, cited in Ride *et al.*, 1962).
	Bernier I	extant	e.g. WAM17061
	Dorre I	extant	e.g. WAM30985
	Edel Land	translocated	Translocated to Heirisson Prong from Dorre I in 1992 (Short *et al.* 1992).
Bettongia penicillata	Faure I	?	WAM9544. Skull found on red sand dune. Could be a sub-fossil.
	Peron Peninsula	1858	BM62.2.8.6 Skull. Listed as 'Sharks Bay' in Thomas (1888).
Lagorchestes hirsutus	Bernier I	extant	e.g. WAM24526
	Dorre I	extant	e.g. WAM27242
	?Carnarvon[2]	1899	BM1939.2908 collected by J.T. Tunney in Feb. 1899, but locality doubtful (see also Ride *et al.* 1962, pp: 8 and 86).
Lagostrophus fasciatus	Bernier I	extant	e.g. WAM34597
	Dorre I	extant	e.g. WAM34599
	Dirk Hartog	translocated	But see Baynes (1990, p. 319). WAM13881 and WAM27239 are from a captive population translocated from Dorre I (Short *et al.*, 1992) in 1974 (R.I.T. Prince, personal communication).
Petrogale lateralis	Kalbarri	1992	Last confirmed sighting in Murchison River gorge was by Roy Harris, Ranger-in-Charge of Kalbarri National Park
Perameles bougainville	Peron Peninsula	1803	Collected at the foot of an elevated dune during the voyage of the Uranie (Quoy and Gaimard 1824, cited in Ride *et al.*, 1962). Several were seen and tracks were common.
	Bernier I	extant	e.g. WAM29360
	Dorre I	extant	e.g. WAM28196
	Edel Land	translocated	Translocated to Heirisson Prong in 1995 from Dorre Island (B. Turner, personal communication).
Macrotis lagotis	Mardathuna Stn	extinct	Reported by an elderly Aboriginal stockman who was living on the station during our 1994 survey – 'long ago'.
Dasyurus geoffroii	Peron Peninsula	1858	BM62.2.8.9 Collected during voyage of HMS Herald. Listed as 'Sharks Bay' in Thomas (1888).
	Sharks Bay	1858	BM62.2.8.7 Listed as specimens l – n (2 males, 1 female) in Thomas (1988).
	Doorawarrah Stn	1982	Captured by Mr Brett Pollock (personal communication).
?Phascogale	?Carnarvon	1928	WAM1028, but specimen appears to be lost. *Antechinus* and *Parantechinus* were registered as '*Phascogale*' in WAM prior to 1940. *Parantechinus macdonnellensis* is extant in the Cape Range, immediately north of the study area.
Pseudomys chapmani	Kennedy Range	old nest	One old pebble mound was located at 24°37'55"S 115°10'59"E (Piggott 1994).
Pseudomys desertor	Bernier I	?	C9745 female skin and skull in Museum of Victoria, collected by G.F. Hill in 1910 (see Appendix 1). Listed as R4997 under *P. praeconis* in Ride *et al.* (1962).
Pseudomys fieldi (now includes *P. praeconis*, see Baynes, 1990).	Peron Peninsula	1858	BM58.12.27.14, a female captured during voyage of HMS Herald (Thomas, 1910).

Table 5 (cont.)

Species	Locality	Last Record	Notes[1]
	Edel Land	translocated	Translocated to Heirisson Prong from Bernier I. in 1994 (P. Speldewinde, personal communication).
	Bernier I	extant	e.g. WAM24587
Leporillus apicalis	Kennedy Range	?	Old Stick-nest Rat nests found in 1996 under breakaways 7 km south of Pharoh's Well and 1 km west of quadrat KE3.
Leporillus conditor	Salutation I	translocated	WAM43167 is from a population translocated from Franklin I in South Australia in 1990 (Robinson, 1995).
Hydromys chrysogaster	Dorre I	extant	WAM40703 Adult female captured in 1993.
Rattus tunneyi	Edel Land	1993	Peter Speldewinde (personal communication) trapped an individual at the tip of Cape Heirisson in March 1993. WAM8751 is one of a series collected at Carrarang Homestead in 1970 by Alex Baynes.
Rattus rattus	Kalbarri	extant	WAM7894.
Canis lupus dingo	throughout	extant	Dogs have been trapped and baited since the 1880s. Systematic aerial baiting since the 1970s. Numbers are now very low with occasional sightings confined to the north-eastern edge of the study area (P. Thompson, personal communication). Possibly always rare in waterless sandplains of southern parts (e.g. three sightings in 43 years on Nerren Nerren — H. Crawford, personal communication).
Camelus dromedarius	Dirk Hartog I	1917	Used to transport goods to outcamps and windmills *ca* 1917; none remain (Burbidge and George 1978).
	Peron Peninsula	?	Used for cartage in the early days; now extinct (Ray Smith, personal communication)
Sus scrofa	Kalbarri	extant	WAM12232. Common in Murchison River gorge.

[1] Voucher specimens prefixed with WAM = Western Australian Museum, BM = British Museum of Natural History (BMNH) or C = National Museum of Victoria.

[2] Furthermore, Thomas (1907, p.772–3) quoted from Shortridge's field-notes from the Balston Expedition (1904–1907): *"...with all these Rat-Kangaroos on the islands off the coast, they are entirely absent from the mainland about here (Carnarvon)."* In a subsequent paragraph on the same page, Thomas clearly included the three Bernier Island wallaby genera in the term "Rat-Kangaroos". Shortridge had been informed by residents of the Carnarvon district that as late as the 1880s: *"... wallabies were as plentiful around Carnarvon as on Bernier Island."* (see Ride *et al.* 1962).

However the November 1995 ground-test of the field sampling detected a total of 34 species-records from the 23 quadrats that we re-trapped, and 14 of these were new quadrat-species intersections (new species records for a quadrat — Table 4). Six of these new intersections were identified gaps (*Notomys alexis* and *Antechinomys laniger* at MD2, *Pseudomys hermannsburgensis* at MD5, *Mus musculus* at NA3, *Notomys alexis* at NA5 and *Sminthopsis dolichura* at ZU4; see 'Methods' and Table 1). Thus, 23.5% (8 of 34 species records) were new non-gap records. This percentage exceeded the arbitrary 10% threshold (see 'Methods'), so we re-sampled all quadrats in March 1996.

The day-eleven point, plotted as a black square on the species accumulation curves (Figure 2), shows the overall increase in quadrat-species intersections during the November 1995 and March 1996 trapping sessions. These sessions improved the quadrat inventories in all survey areas (campsites) except CU, EL and BB. The twelfth and final point on each curve indicates the number of additional intersections contributed by the invertebrate buckets. It is plotted as a black circle. The invertebrate buckets contributed four new quadrat-species intersections to the mammal inventory — *Antichinomys laniger* at BO2 and GJ4, *Sminthopsis hirtipes* at NE2, and *Pseudomys hermannsburgensis* at NE3.

Trap Design

In the fenced pitfall-trap arrays set for vertebrates, the buckets (450 mm deep and 300 mm diameter) added little to the survey compared with the 500 mm deep and 125 mm diameter tubular pits. Allowing for the 3:1 ratio in tube-to-bucket trapping effort during the October and May sessions respectively (3660:1220 and 3704:1244), the buckets caught fewer individual mammals than the tubular pits, irrespective of species (Table 3). On average, they were less than half as effective. Even so, most of the Hopping Mice (*Notomys*) caught in the tubes

Table 6 A selection of previous Carnarvon Basin locality records for the species recorded during our field survey.

Species	Locality	Most Recent Record
Macropus rufus	Eurardy	WAM3241, 27°35'S 114°41'E
	Toolonga	27°00'S 115°00'E (Burbidge *et al.*, 1980).
	Hamelin	WAM4965, 26°25'S 114°11'E
	Meeragooli	WAM3242, 24°47'S 114°06'E
	Yalobia	WAM3240, 24°16'S 114°02'E
	Minnie Creek	WAM9604, 24°15'S 115°30'E
Macropus robustus	Zuytdorp	B918, 26°48'S 114°14'E (Bannister, 1969).
	Yaringa	WAM26889, 25°56'S 114°19'E.
	Boologooro	WAM19966, 24°18'S 113°59'E.
	Nilemah	WAM4964, 26°25'S 114°03'E.
	Edel Land	Seen at Baba Point in 1991 by Nich Hall, and on Heirisson Prong in 1995 by Phil Boglio (personal communication).
Macropus fuliginosus	Kalbarri	WAM19992.
Tarsipes rostratus	Kalbarri	WAM7895.
Sminthopsis crassicaudata	Kalbarri	WAM7896.
	Murchison House	B914, 27°10'S 114°14'E (Bannister, 1969).
Sminthopsis dolichura	Wandina	WAM28103, 27°59'S 115°38'E.
	Eurardy	WAM40705, 27°34'S 114°40"E.
	Kalbarri	WAM34141.
	Dirk Hartog I	WAM18828.
	Monkey Mia	WAM18490, 25°50'S 113°37'E.
Sminthopsis granulipes	Kalbarri	WAM14926.
Sminthopsis hirtipes	Peron Peninsula	WAM46309.
	Kalbarri	WAM10208.
Notomys alexis	Kalbarri	WAM15259.
	Wolarry	WAM18026, 26°47'S 115°18'E.
	Wandagee	WAM15291, 23°37'S 114°29'E.
Pseudomys albocinereus	Kalbarri	WAM12468.
	Cooloomia	WAM20925, 26°58'S 114°09'E.
	Dirk Hartog I	WAM11914.
	Dorre I	WAM16115.
	Bernier I	WAM24340.
	Peron Peninsula	P. Speldewinde (perssonal communication, September 1995).
Pseudomys hermannsburgensis	Cooloomia	WAM20926, 26°58'S 114°09'E.
	Dirk Hartog I	WAM18779.
	Williambury	WAM28119, 23°52'S 115°09'E.
Mus musculus	Kalbarri	WAM7888.
	Cooloomia	WAM17464, 26°58'S 114°09'E.
	Carrarang	WAM8775, 26°15'S 113°19'E.
	Dirk Hartog I	WAM18786.
	Bernier I	Recorded by Shortridge in 1906 (Ride *et al.*, 1962) but not collected during intensive trapping programs during the 1980s and 1990s (K.D. Morris, personal communication).
	Bulbarli	WAM8716, 23°31'S 113°45'E.
*Oryctolagus cuniculus**	*circa.* 1900 – 1910	Williams *et al.* (1995)
Felis catus	Dirk Hartog I	WAM13599. Introduced. Carter (1917) reported that they were becoming numerous on the island. Extant.
	Bernier I	Introduced (Thomas 1907 and Shortridge 1910, cited in Ride *et al.* 1962, p. 84). Now extinct.
Vulpes vulpes	Murchison	WAM24440, 27°08'S 113°58'E. The first fox was trapped in the late 1920s about 20 km south of Coburn House (H. Crawford, personal communication).

Table 6 (cont.)

Species	Locality	Most Recent Record
*Ovis aries**	Dirk Hartog I	WAM357. Introduced, extant.
	Dorre I	WAM14976. Introduced, but now extinct.
	Bernier I	Introduced (Ride *et al.*, 1962, p. 83), but now extinct.
	Peron Peninsula	Introduced, but recently de-stocked (Thomson and Shepherd, 1995).
*Capra hircus**	Kalbarri	WAM12233, extant.
	Dirk Hartog I	Burbidge and George (1978), extant.
	Bernier I	WAM4783. Introduced in 1899, but eradicated in 1984 (Morris, 1985, 1987).
*Bos taurus**	Peron Peninsula	De-stocked in early 1990s (Ray Smith, personal communication).
*Equus caballus**	Dirk Hartog I	12 females were present in 1972 (Burbidge and George, 1978).
	Bernier I	Introduced, *fide* Ride *et al.* (1962, p. 83), but now extinct.
	Peron Peninsula	Used for cartage in the early days; now extinct (Ray Smith, personal communication).

* Occur or have occurred on all pastoral leases throughout the study area.

were sub-adult or pregnant. The November 1995 and March 1996 trapping sessions revealed that the problem was overcome if a baffle was added to prevent adult *Notomys* and *Antechinomys* from jumping out (1.9 versus 0.8 *Notomys* per 100 trapnights, from Table 3). We concluded that the tubes should have been even deeper.

The five invertebrate buckets set on each quadrat for one year (*ca* 114 000 bucket-nights) yielded a total of 39 mammal specimens (8 species): 15 *Notomys alexis*, two *Pseudomys albocinereus*, six *P. hermannsburgensis*, two *Sminthopsis dolichura*, two *S. hirtipes*, five *S. macroura*, three *S. youngsoni* and four *Antechinomys laniger*. In comparison, 57 mammal specimens (12 species) were captured during 2476 vertebrate bucket nights (excluding tube captures) on the same set of quadrats (Table 3). The differences between these trap-types were the wire filters, small openings and glycol-formalin fluid in the invertebrate buckets, and the presence of two five-metre-long drift fences radiating out from each vertebrate bucket. Clearly, these made a difference! Only *A. laniger* was captured more efficiently by the invertebrate buckets.

The Fauna

Data on the 38 species of non-volant mammal captured in the study area prior to our field survey are provided in Tables 5 and 6. Twenty-eight are indigenous and 10 have been introduced during the last few centuries. One additional indigenous species has been re-introduced to the study area recently (*Leporillus conditor*); it was previously known as bones in sub-fossil deposits (Table 5; Appendix 2).

Nineteen extant indigenous species, as well as nine introduced species, were encountered during our sampling programme (Table 7). The indigenous component comprises four rodents, ten dasyurids, one honey possum, three macropods and the Echidna. A representative collection of specimens and frozen tissues has been lodged in the Western Australian Museum. Species nomenclature in this report mostly follows Strahan (1995), although *Dasycercus hillieri* (Thomas, 1905) has since been resurrected.

Patterns in the Richness and Composition of Assemblages

Only the small ground-dwelling mammals of less than 100 g adult body weight were used in quantitative analyses because these were the only species that could be systematically sampled by the trapping system. Thus, the trap-effort values in Table 2b provide a relative measure of sampling effort. Other vertebrate survey methods added virtually no data to the presence-absence matrix of small-ground-mammal occurrences, aside from the *Antechinomys laniger* that forced their way into invertebrate pits on GJ4 and BO2.

The results of the numerical classifications of the small ground mammal data are presented as a re-ordered data matrix in Table 8. An average of 2.8 (1–5, n = 63) small, indigenous ground-mammal species were recorded per quadrat, if we include the five quadrats from which only one such species was recorded (BB2, BO4, GJ2, MD3 and MD4). Neither Table 8, nor the stepwise structure apparent in its associated dendrogram (Figure 3a), suggested a pattern of discrete clusters. Thus, for the purposes of interpretation, species were ordinated in 3-dimensional space using Semi-strong Hybrid Scaling (Belbin, 1991), then a Minimum Spanning Tree was superimposed (Figure 3b).

- Species-group_1 and _2 are species of the semi-arid to mesic temperate regions of south-western Australia (Strahan, 1995; Figure 4a–b).

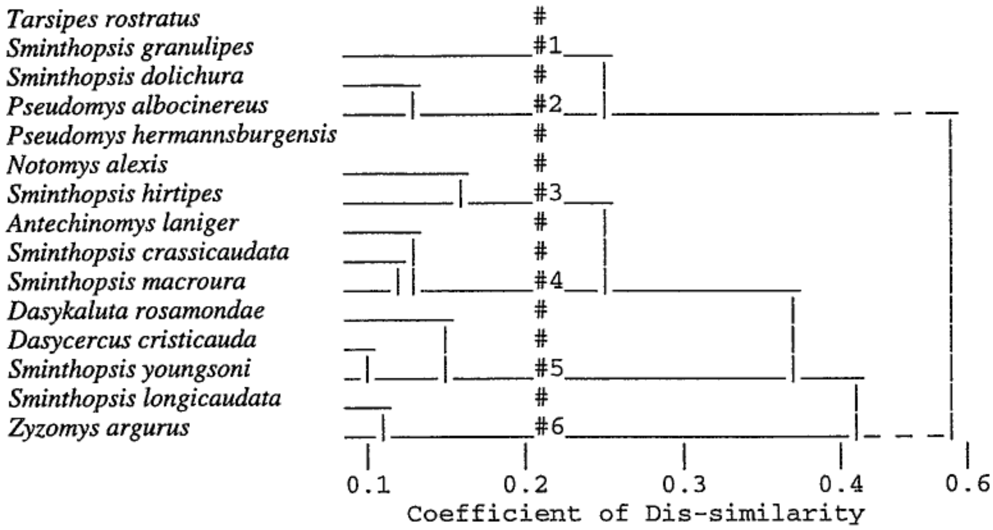


Figure 3a Indigenous small ground-dwelling mammals classified according to their co-occurences at the same quadrats. The introduced rodent *Mus musculus*, and quadrats where only a single species was recorded, are excluded.

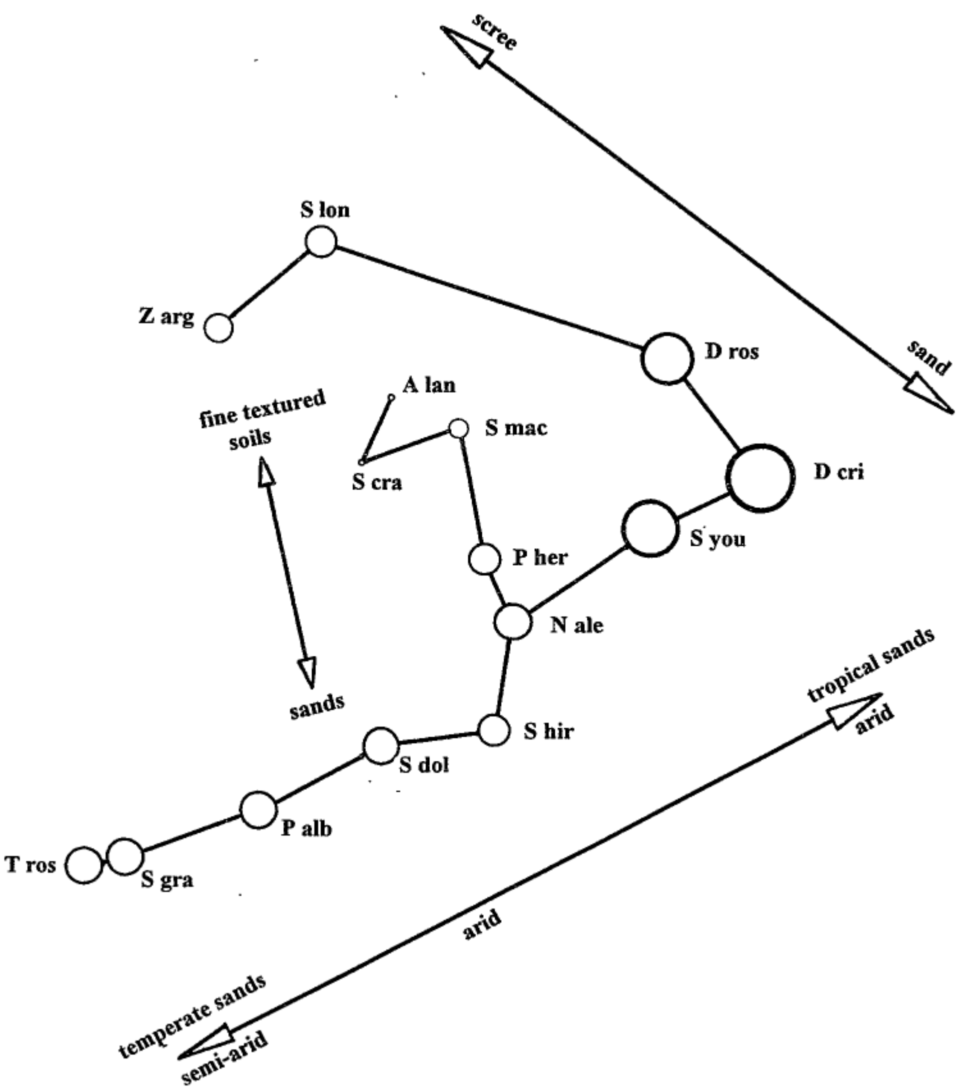


Figure 3b Three-dimensional ordination (Belbin, 1991) of the small ground-dwelling mammals according to their co-occurrences on quadrats (stress = 0.05, excluding *Mus musculus* and quadrats with less than two species). The third dimension is indicated by circle diameters. A Minimum Spanning Tree has been superimposed. The point labels comprise the first letter of the genus-name and the first three letters of the species-name, as listed in Figure 3a.

In the study area, they occur south of Shark Bay: Group_1 comprises species confined to coastal sands mantling limestone while those in Group_2 extend further inland on a wider array of sandy soils.

- Species-group_3 comprises species whose primary habitats are the sandplains and dunefields of Australia's arid zone (Strahan, 1995; Figure 4c), although *Sminthopsis hirtipes* is confined to its temperate latitudes. The two rodents were ubiquitous in the study area.
- Species-group_4 comprises three dasyurids that favour fine textured soils (sandy loams to clays) throughout their ranges in the study area and elsewhere in arid Australia (Strahan, 1995; Figure 4d–f). Unlike *Sminthopsis macroura*, *S. crassicaudata* was confined to samphire comm-unities associated with saline evaporite surfaces at the bottom of the landscape. The exceptions were two juveniles and a sub-adult captured in saltbush communities (at BO1 and BB1), immediately adjacent to extensive salt pans (known as playas).
- Species-group_5 comprises three dasyurids for which sandy surfaces of Australia's tropical arid regions are primary habitat (Strahan, 1995; Figure 4g, i).
- Species-group_6 comprises a rodent and a dasyurid that are confined to outcrop and rocky scree environments in tropical Australia (Strahan, 1995; Figure 4h, j). The dasyurid is confined to the arid zone.

Gradients in the composition of the small ground mammal assemblages are overt in Table 8. Subjectively, they can be explained in terms of the study area's climatic gradients and substrate patterns (Figure 5). A quantitative analysis of small mammal occurrences in terms of the physical attributes of the quadrats revealed an array of highly significant correlations at the four-group level in the classification structure (Table 9). Allowing for the strong inter-correlations between many of these physical attributes (see Appendix I), two distinct

Table 7 Mammals recorded in the Carnarvon Basin study area. Location codes refer to survey areas (=campsites) and quadrats. For instance, KE1 = quadrat No. 1 in the Kennedy Range (KE) survey area, while KE1-3,5 = quadrats KE1, KE2, KE3 and KE5, and (KE) = indicates a record that was in the KE survey area but not actually on one of the quadrats. Campsite names and locations are provided in Figure 1.

Species	Location
Tachyglossus aculeatus	BB2,4,5; BO1; (GJ); KE1,2; MD1,3; MR3; NE3-5; PE1,2; WO1,2,4; ZU3.
Macropus rufus	BB2; BO1-4, CU1,2,4-6; GJ1,3; MD1,2,4,5; MR1-3; WO2.
Macropus robustus	BB2,4; CU1,5,6; GJ1; KE3,5; (MR); (NE); PE2.
Macropus fuliginosus	(NE); ZU1-5.
Bettongia lesueur (old warren)	WO4.
Tarsipes rostratus	ZU1,2.
Antechinomys laniger	BO2; GJ4; MD2.
Dasykaluta rosamondae	KE1-3.
Dasycercus cristicauda	KE2.
Sminthopsis crassicaudata	BB1,3; BO1,2; CU1; NA1; PE1.
S. dolichura	EL1,2; NA2-5; NE1-5; PE1-5; WO1, ZU1-5.
S. granulipes	ZU1,2.
S. hirtipes	MD5; NA3,4,5; NE2,3; (PE); WO2,3; ZU4.
S. longicaudata	GJ1; KE3.
S. macroura	BB1,3; BO2; CU1; KE3-5; MD5; MR1; WO3-5.
S. youngsoni	CU2-5; KE1,2; MR2-5.
Notomys alexis	BB1,2,4,5; BO1-5; CU2-6; GJ2,3,5; KE1,2,4,5; MD1,4; MR1-5; NA2-5; NE1-3,5; PE2-5; WO1-3; ZU3,4.
Pseudomys albocinereus	EL1,2; (PE); ZU1-5.
Pseudomys hermannsburgensis	BB1,3-5; BO1-3,5; CU1-6; EL2; GJ1,3-5; KE1-4; MD1-3,5; MR1,2,4,5; NA1-4; NE1,3-5; PE1-3,5; WO2-5; ZU5.
Zyzomys argurus	GJ1; (KE).
Leporillus (old nest)	GJ1; (KE).
Mus musculus	BB5; CU1,3,4,6; GJ5; MD2,3; (MR); NA1,3; PE1,2,5.
Oryctolagus cuniculus	BB1-5; BO2-5; CU1,2,6; EL1,2; GJ4,5; MD1,3; MR1; NA1-5; PE1-5; ZU2-4.
Felis catus	BB2,4,5; BO2,4,5; EL1,2; GJ2; KE1; (MR); NE3,5; PE2-5; WO5; ZU1.
Vulpes vulpes	BB1,2,4,5; BO2-5; CU1,5,6; EL2; GJ1-5; KE4,5; MD1-3; MR5; NA1-3; NE1,2,4; PE1-5; WO1-3,5; ZU1-5.
Ovis aries	BO1-5; CU1-6; EL1,2; GJ2-5: MD1-5; MR2, NA1, NE1-5; WO1-5.
Capra hircus	BB1-5; BO5; CU1,4; KE3,4; (GJ); MD1-3; MR1; NA2,3; NE3,5; PE1,4,5; WO2-5; ZU1-5.
Camelus dromedarius	KE4,5.
Bos taurus	BO3; EL1; GJ1; KE5.
Equus caballus	BB3; GJ5; (WO).

Table 8 Data matrix of small, ground-dwelling, indigenous mammals, excluding the five quadrats from which we recorded only a single species. The quadrats have been re-ordered according to the similarities in their species composition, and the species have been re-ordered according to their co-occurrences at the same quadrats. Quadrat codes are printed vertically. Quadrat locations, by campsite, are shown in Figure 1.

```
Species Groups                                        Quadrat Groups
                                1  2     3               4  5      6       7 8  9        10
                                ZZ|ZZZEE|NPPPNNPWNNNNNWW|PN|BNBBCB|KWWMKMK|G|GM|BBGCBBGM|KKCCCCMMMM
                                UU|UUULL|AEEEEEEOAAEAEOO|EE|OAOBUB|EOODERE|J|JD|OOJUBBJD|EEUUUURRRR
                                12|34521|223515413435223|14|112113|3455415|1|42|35364551|1223452453

1 Tarsipes rostratus            **|     |               |  |      |       | |  |        |
  Sminthopsis granulipes        **|     |               |  |      |       | |  |        |
                                --+-----+---------------+--+------+-------+-+--+--------+----------
2 Sminthopsis dolichura         **|*****|*************  |**|      |       | |  |        |
  Pseudomys albocinereus        **|*****|               |  |      |       | |  |        |
                                --+-----+---------------+--+------+-------+-+--+--------+----------
3 Pseudomys hermannsburgensis     |  ** |******  ***  **|**|******|****** |*|**|********|*********
  Notomys alexis                  |**   |***************|  |* **  |    ***| |  |********|**********
  Sminthopsis hirtipes            | *   |        *******|  |      |   *   | |  |        |
                                --+-----+---------------+--+------+-------+-+--+--------+----------
4 Antechinomys laniger            |     |               |  |  *   |       | |**|        |
  Sminthopsis crassicaudata       |     |               |* |******|       | |  |        |
  Sminthopsis macroura            |     |              *|  |  ****|*******| |  |        |
                                --+-----+---------------+--+------+-------+-+--+--------+----------
5 Dasykaluta rosamondae           |     |               |  |      |*      | |  |        |**
  Dasycercus cristicauda          |     |               |  |      |       | |  |        | *
  Sminthopsis youngsoni           |     |               |  |      |       | |  |        |**********
                                --+-----+---------------+--+------+-------+-+--+--------+----------
6 Sminthopsis longicaudata        |     |               |  |      |*      |*|  |        |
  Zyzomys argurus                 |     |               |  |      |       |*|  |        |
SPECIES RICHNESS                44 34332 333333224443334 32 325433 4223332 3 22 22222222 4533333332
```

Table 9 Significant relationships between quadrat physical attributes and the small ground-dwelling mammal classification structure partitioned at the four-group level. KW = Kruskall Wallis 'H' value; *** = probability < 0.001. Average (standard deviation) values are listed for each of the four quadrat-groups.

Attribute*	Classification Group				KW
	1	2	3	4	
No. of quadrats	7	17	16	18	
Tann	21.0 (0.2)	21.7 (0.3)	22.9 (0.6)	23.2 (0.4)	43 ***
PwarQ	30 (1)	41 (7)	63 (12)	73 (12)	42 ***
TwetQ	16.3 (0.3)	16.8 (0.5)	18.6 (3.1)	19.7 (3.8)	39 ***
TcldQ	15.0 (0.3)	15.5 (0.5)	16.5 (0.6)	16.9 (0.6)	37 ***
TwarQ	27.3 (0.1)	28.0 (0.3)	29.2 (1.0)	29.2 (0.9)	35 ***
Latitude	27.1 (0.3)	26.5 (0.5)	25.1 (0.7)	24.6 (0.4)	43 ***
PcldQ	186 (9)	129 (18)	91 (17)	92 (16)	36 ***
PwetQ	196 (6)	143 (19)	111 (18)	115 (19)	33 ***
Pann	316 (14)	245 (18)	223 (13)	233 (16)	30 ***
TdryQ	25.1 (0.1)	23.4 (0.3)	22.8 (0.8)	22.6 (0.8)	28 ***
% silt	1.3 (1.1)	1.0 (0.5)	4.3 (2.8)	1.2 (0.7)	25 ***
Moisture Index	0.65 (0.08)	0.64 (0.06)	0.99 (0.26)	0.65 (0.07)	34 ***
Soil texture	1.1 (0.3)	1.5 (1.9)	2.5 (1.0)	1.1 (0.3)	30 ***
K(HCO_3)	27 (12)	88 (147)	219 (103)	85 (51)	30 ***

* P = precipitation, T = temperature, war = warmest, ann = annual, cld = coldest, Q = Quarter (season), soil texture and moisture index measured in the mid-profile (Wyrwoll, Stoneman, Elliott and Sandercock, 2000).

Table 10 Re-construction of the original (Late Holocene) indigenous mammal fauna, excluding bats and introduced species (such as *Mus musculus*, as well as translocated populations). Only the most recent record is listed; earlier records (e.g. historical or sub-fossil) of species from a sector are not listed if an extant record is available.

Data are derived from the following sources: 'a' (from Table 7), 'b' (from Table 6), 'c' (from Table 5), and 'e' (sub-fossil records from Appendix 2: Tables 1–8 as relevent).

The boundaries of the nine sectors distinguished in the study area are shown in Figure 1: 1 = Kalbarri (includes ZU1-5, NE1-2 and NA2-5), 2 = Edel Land, 3 = Dirk Hartog I, 4 = Bernier and Dorre Is, 5 = Peron Peninsula, 6 = Yaringa, 7 = Cuvier, 8 = Pells Range, 9 = Kennedy Range.

SPECIES	SECTORS								
	1	2	3	4	5	6	7	8	9
Tachyglossus aculeatus	a	e			a	a	a	a	a
Macropus rufus	b					a	a	a	a
Macropus robustus	b	b			a	b	a	a	a
Macropus fuliginosus	a					b			
Macropus eugenii	c								
Bettongia lesueur		e	c	c		a*	e		
Bettongia penicillata		e	e		c				
Lagorchestes hirsutus				c	e				
Lagostrophus fasciatus				c	e				
Onychogalea lunata					e				
Petrogale lateralis	c								
Macrotis lagotis						e	e	c	c
Chaeropus ecaudatus						e		e	
Perameles bougainville	e	e	e	c	c	e	e	e	
Isoodon auratus						e	?e	e	
Isoodon obesulus	e	e							
Tarsipes rostratus	a								
Antechinomys laniger						a	a	a	
Dasyurus geoffroii		e	e		c	c	e		
Dasykaluta rosamondae							b	e	a
Dasycercus cristicauda	e	e	e		e	e	e	e	a
Parantechinus apicalis	e	e	e						
Phascogale calura		e			e	e	e	e	
Sminthopsis crassicaudata	b				a	a	a		
Sminthopsis dolichura	a	a	b		a	a			
Sminthopsis granulipes	a								
Sminthopsis hirtipes	a				b	a	e		
Sminthopsis longicaudata								a	a
Sminthopsis macroura						a	a	e	a
Sminthopsis youngsoni							a		a
Hydromys chrysogaster				c					
Leggadina forresti								e	
Notomys amplus							e	e	e
Notomys alexis	a	e			a	a	a	a	a
Notomys longicaudatus		e				e		e	e
Pseudomys albocinereus	a	a	b	b	b		e		
Pseudomys chapmani									c
Pseudomys desertor		e	e	c			e		
Pseudomys fieldi	e	e	e	c	c	e	e	e	e
Pseud. hermannsburgensis	a	a	b		a	a	a	a	a
Pseudomys nanus	e	e				e		e	e
Pseudomys shortridgei	e	e	e						
Rattus tunneyi	e	c			e	e	e	e	e
Zyzomys argurus								a	a
Zyzomys pedunculatus								e	
Leporillus conditor	e	e	e		e	e	e		
Leporillus apicalis		e			e	e	e	e	?c
Canis lupus dingo	c	c			c	c	c	c	c

* as an old abandoned warren system, now used by rabbits.

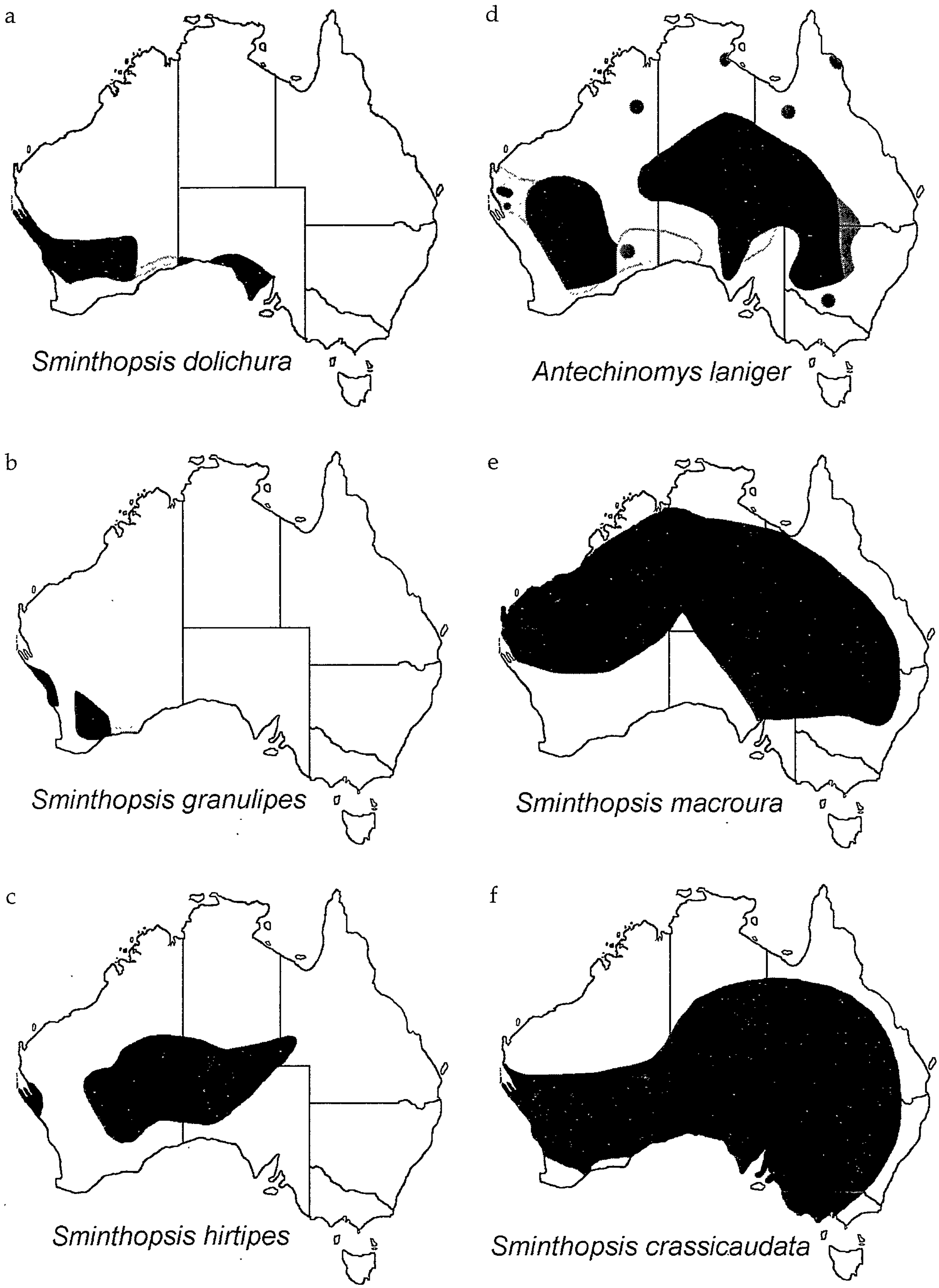


Figure 4 Geographical ranges of Australian mammals updated from Strahan (1995) by N.L. McKenzie, A.A. Burbidge and A. Baynes with information supplied by numerous field mammalogists. Pale grey = Late-Holocene sub-fossil, dark grey = historic (>30 years ago), black = extant.

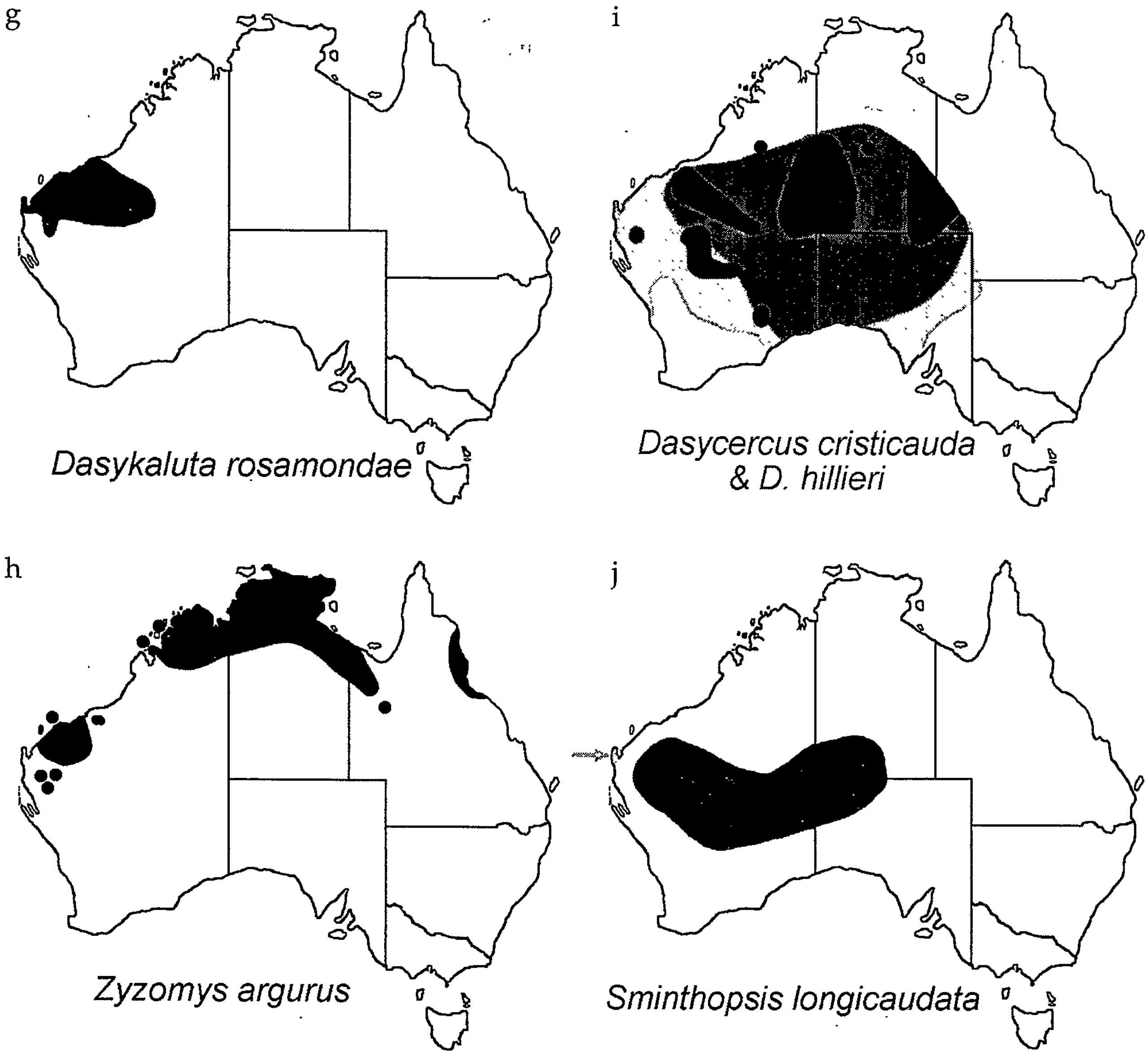


Figure 4 (cont.)

sets of relationships emerged. The tightest fits involved 'annual average temperature' (Tann) which was a reciprocal of latitude (Lat) and related to 'how tropical', then within that, 'percentage silt in the top 10 cm of the soil profile' (Figure 6). Soil profiles with high silt percentages in the upper profile also had high mid-profile 'soil texture' and 'moisture index' values (see Wyrwoll, Stoneman, Elliott and Sandercock, 2000). At the ten-group level, soil phosphorus separated Group_5 from Group_6, and Group_9 from Group_10 (Figure 6). Group_5 quadrats all have saline soils, and were set low in the landscape. PE1, the only saline quadrat not classified to Group_5, was on the floor of a small 'playa' that was occasionally traversed by mammals from the surrounding sand dunes.

Thus, there is a gradient in the species composition of the small ground-mammal assemblage that extends from the semi-arid temperate to the arid tropical parts of the study area. Within the arid tropical part, another compositional gradient extends from sands to finely-textured soils. Certain species were confined to scree and outcrop surfaces.

Fauna Re-construction

The re-constructed Late Holocene fauna of non-volant mammals is listed in Table 10. Forty-eight indigenous species are known: one monotreme, one Honey Possum, 13 dasyurids, five bandicoots, 10 macropods, 17 rodents and one canid (the dingo). Relevant, updated distribution maps are provided in Figure 7. In terms of body weight and phylogeny, the surviving indigenous ground-dwelling mammals are a biased sub-set of the Late-Holocene fauna (Table 11). Nearly all indigenous placental and marsupial species with an adult body weight between 30 g and 4000 g are

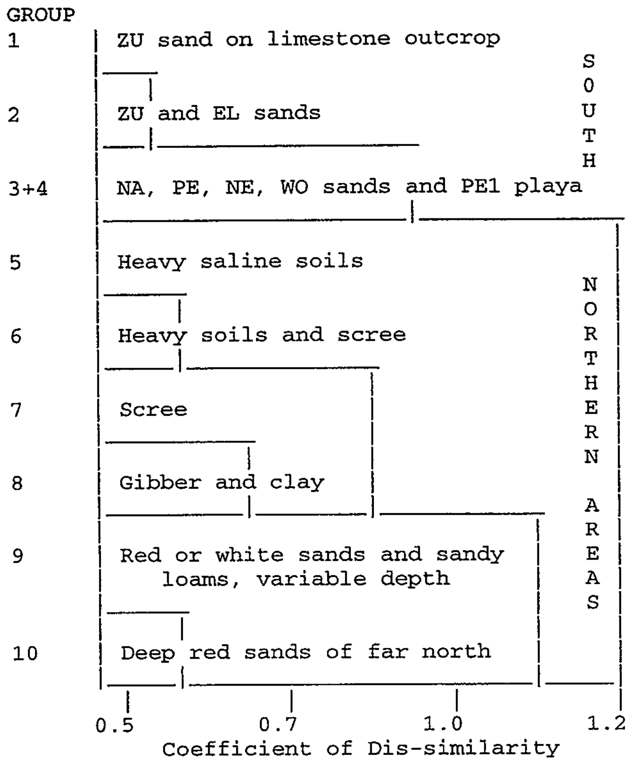


Figure 5 Quadrats classified according to similarities in small, indigenous, ground-dwelling mammal species composition. The classification structure is displayed down to the ten-group level.

extinct, irrespective of their phylogenetic relationships.

Our analysis of geographic patterns in this fauna (excluding the macropods and Sector-4, the off-shore island sector, see 'Methods') is summarised in Figure 8. Three compositionally distinct regions were distinguished, comprising:

- the three south-western sectors — Kalbarri, Edel Land and Dirk Hartog (see Figure 1),
- the three central and north coastal sectors — Peron Peninsula, Yaringa and Cuvier and
- the two northern inland sectors — Pells Range and Kennedy Range.

'Annual average temperature' (Tann) provided a tight fit to the observed compositional patterns, although 'average temperature in the warmest quarter' (TwarQ) and 'average precipitation in the coldest quarter' (PcldQ) showed similarly significant relationships.

DISCUSSION

Extant

Knowledge of the composition, distribution and status of the ground mammal component of the study area's indigenous fauna prior to our survey was scant, being based on 672 records held in museum collections, mostly from the Shark Bay islands and Kalbarri National Park. For instance 470 of these records came from Bernier, Dorre or Dirk Hartog Islands.

Of the 19 indigenous species encountered during the field programme (Table 7), five were the first records for the study area (*Antechinomys laniger, Dasycercus cristicauda, Dasykaluta rosamondae, Sminthopsis longicaudata* and *Zyzomys argurus*), although *A. laniger* and *D. cristicauda* were previously known as sub-fossils. Our work extended the known distribution of six others by 50 km or more (*Tarsipes rostratus, Sminthopsis crassicaudata, S. granulipes, S. hirtipes, S. macroura* and *S. youngsoni*). For instance, even BIOCLIM-generated predictions of the geographical range of *S. hirtipes* (Dickman *et al.*, 1993a) excluded NA3-5 and MD5 (see Table 7 and Figure 1).

Combining the results of our field survey with the historical review (Tables 5, 6 and7), a total of 35 non-volant indigenous and 10 introduced mammals have been recorded as extant in the study area since European visits began, although most of the medium-sized mammals have disappeared during the last 100 years. Of the small mammals likely to be present, we did not record *Pseudantechinus macdonnellensis* or *Ningaui timealeyi,* although both are known from the northern end of the Carnarvon Basin, outside of our study area (Baynes and Jones, 1993). In view of their geographical ranges elsewhere in Western Australia (Strahan, 1995), we expected to find these two species extant, and/or in sub-fossil deposits, in the Kennedy Range area (Figure 1).

The composition of the study area's small ground-mammal assemblages changes along climatic and soil-texture gradients:

- from the 'semi-arid temperate' climate in south-western parts of the study area, to the 'arid-temperate' and 'arid-tropical' climates of its south-eastern and northern parts, respectively, and
- at more local scales, from sands to fine-textured soils, while certain species are confined to screes and rock outcrops.

Similar patterns have been noted in other Western Australian bioregions, such as the Murchison, Coolgardie, Nullarbor and Hampton (Boscacci *et al.*, 1987; How *et al.*, 1988; McKenzie *et al.*, 1992, 1994; Burbidge *et al.*, 1995).

Within the study area, as well as throughout their ranges elsewhere in Australia (e.g. Strahan, 1995; McKenzie *et al.*, 1994):

- *Dasycercus cristicauda, Dasykaluta rosamondae, Sminthopsis youngsoni, S. hirtipes* and *Pseudomys albocinereus* favour sandy surfaces (*D. rosamondae* will also occur on gravelly loams),
- *Sminthopsis longicaudata, Zyzomys argurus* and *S. granulipes* favour outcrop surfaces, and

Annual average temperature (°C). Kruskall Wallis = 42.7, Probability = 0.0000

```
      20.8             21.5            22.3            23.0       23.6
N GRP +----------------+---------------+---------------+--------------+
7   1 *===M===*
17  2               *======M======*
16  3                                     *============M============*
18  4                                              *========M========*
```

Percent silt. (Kruskal-Wallis = 25.5, P. = 0.0000).

```
        0.5            3.0            5.5         7.5
N  GRP  +---------------+--------------+-------------+
7   1   *====M======*
17  2   *==M==*
16  3          *===============M=================*
18  4   *===M===*
```

Moisture index (m_mind). Kruskal-Wallis = 33.7, Probability = 0.0000

```
        0.6              0.8             1.05              1.3
N  GRP  +-----------------+----------------+------------------+
7    1   *==M======*
17   2   *M====*
16   3            *=====================M====================*
18   4   *=M======*
```

Soil phosphorus (P_HCO_3 ppm). Kruskal-Wallis = 25.2, Probability = 0.003.

```
        1.0                8.0               15.0              22.0
N  GRP  +------------------+-----------------+-----------------+-----
2    1  *M=*
5    2  *===================M=======================*
15   3  *=========M=============*
2    4      *=============M=============*
6    5                     *==================M===================*
7    6           *=====M=======*
1    7                     *
2    8                     *=M*
8    9                      *====M=====*
10  10     *===M===*
```

Soil electrical conductivity (ms/m). Kruskal-Wallis = 15.5, Probability = 0.08.

```
        1.0                457               913               1368
N  GRP  +------------------+-----------------+-----------------+-----
2    1  *
5    2  *
15   3  *
2    4  *=====================================M=====================>
6    5  *==============M===============*
7    6  *
1    7  *
2    8  *=M=*
8    9  *
10  10  *
```

Figure 6 Physical attributes of the quadrat-groups derived by classifying the 63 quadrats in terms of similarities in their small, indigenous, ground mammal species composition (the 4– and 10–group level in Figure 5). Soil attributes were measured from the top 10 cm of the soil profile. GRP = group. N = number of quadrats in each group. M = mean and * = standard deviation.

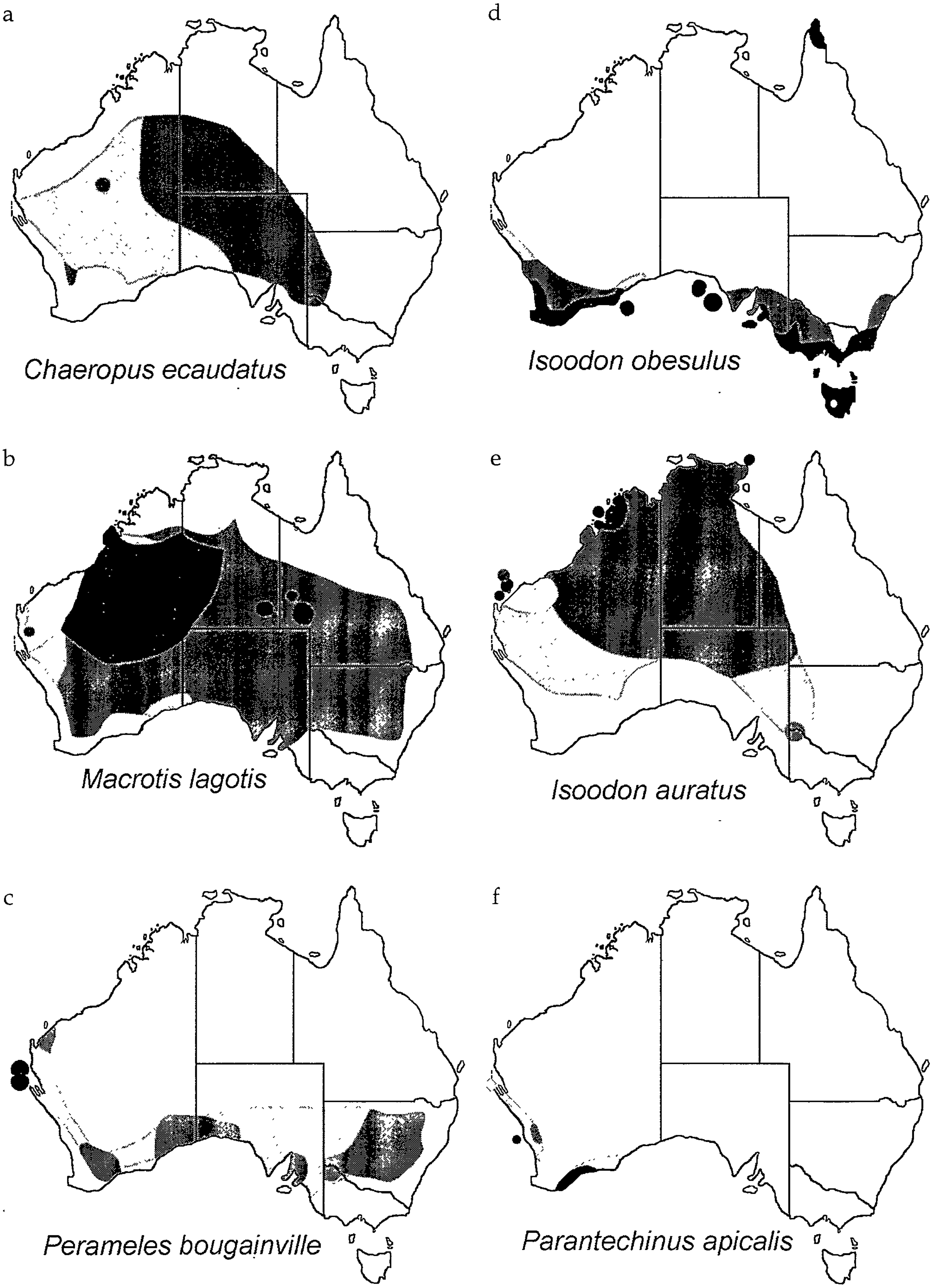


Figure 7 Geographical ranges of certain Australian mammals, updated as necessary from Strahan (1995) by N.L. McKenzie, A.A. Burbidge, A. Baynes and numerous other field mamalogists. Pale grey = Late Holocene subfossil, dark grey = historic (>30 years ago), black = extant.

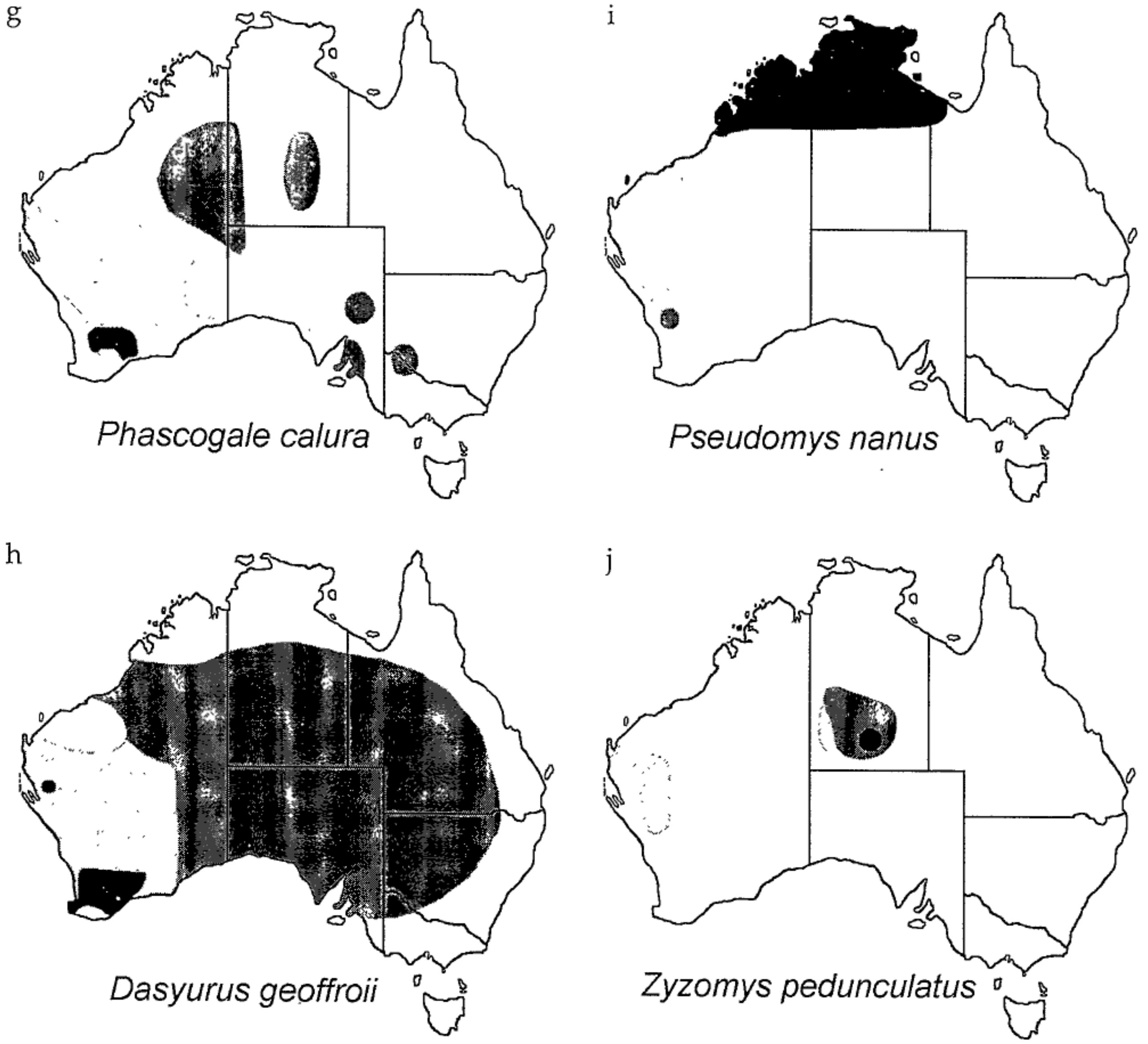


Figure 7 (cont.)

- *Sminthopsis macroura, S. crassicaudata* and *Antechinomys laniger* favour fine textured surfaces such as alluvial loams, clays and gibber surfaces.

Figure 6 confirms the tightness of such relationships between species and particular substrate-types in the study area. In combination with differences in the functional anatomy of species' foot pads, these observations support the view that 'stationarity' in habit-use (*sensu* Hengeveld, 1994) characterizes many small Australian dasyurid species. Among these dasyurids for instance, the sand specialists *Sminthopsis youngsoni* and *S. hirtipes* have bristly foot pads, whereas rock specialists *S. longicaudata* and *S. granulipes* have striated or exceptionally granulated foot pads.

In contrast, *Pseudomys hermannsburgensis* and *Notomys alexis* occupied virtually all habitats, from upland sand dunes, outcrop surfaces and sand plains (Permian, Tertiary and Quaternary) to alluvial plains and samphire pans (Quaternary) at the bottom of the landscape. In the Coolgardie and southern Murchison districts, elsewhere along this semi-arid biogeographic interzone, *P. hermannsburgensis* favours the well-drained, older (Tertiary) surfaces high in the landscape while a morphologically equivalent species (*P. bolami*) occupies the younger Quaternary surfaces low in the landscape (McKenzie *et al.*, 1992, 1995). The ubiquity of both *P. hermannsburgensis* and *N. alexis* may result from the recent disappearance of a range of other rodents from the study area (e.g. *Pseudomys fieldi, P. desertor, P. nanus, P. shortridgei, Notomys amplus* and *N. longicaudatus* — Table 10), although density-dependent habitat selectivity (Rosenzweig and Abramski, 1986) associated with their huge population fluctuations (see below) provides an

Table 11 Body weight, phylogeny and current status of the Carnarvon Basin study area's re-constructed ground-dwelling mammal fauna, excluding island populations. Species not recorded in mainland parts of the study area during the last 30 years are treated as extinct there.

Weight (g)	1–20	21–200	201–2000	2001–20 000	20 001+
MACROPODS (10 species)					
Extant				2	3
Extinct			4	1	
BANDICOOTS (5 species)					
Extant					
Extinct		1	4		
DASYURIDS (13 species)					
Extant	6	4	1		
Extinct		2			
RODENTS (16 species)					
Extant	2	4			
Extinct	1	8	1		
TOTAL (46 species)					
Extant	8 + 1[a]	8	1	2 + 1[b]	3
Extinct	1	11	9	1	0

[a] Honey Possum, *Tarsipes rostratus*
[b] Echidna, *Tachyglossus aculeatus*

alternative mechanism. Extinction may also explain why the average number of extant small, indigenous, ground-dwelling mammal species per quadrat is low compared with quadrats in similarly arid areas elsewhere in Western Australia: 2.8 ± 0.9 (s.d.), n = 63, from an average of 28.5 drift-fence nights per quadrat, versus 3.8 ± 1.2 (n = 21) from 20.3 drift-fence nights per quadrat in the southern Murchison (McKenzie *et al.*, 1992, 1994; Burbidge *et al.*, 1995).

Nevertheless, small mammal densities were low during the period of our field survey. This may have been caused by the relatively dry years that preceded our study. Data in Table 3 indicate a 5% return (at best), whereas McKenzie *et al.* (1994) recorded a 16.9% return (202 small ground-dwelling mammal specimens for 199 x 6 pit-trap nights of effort = 199 drift-fence nights) in the adjacent Murchison district, and McKenzie *et al.* (1983, Table 21) recorded an 11.6% return (109 specimens for 157 x 6 pit-trap nights) in the Great Sandy Desert, after unusually wet seasons in these similarly arid districts. All studies used the same fenced pit-trap design. Elsewhere in Australia's arid zone, up to a hundred-fold increase in the density of highly fecund rodents such as *Notomys alexis* and *Pseudomys hermannsburgensis* has been noted after unusually wet seasons (Masters, 1993; Predavec, 1994; Smith and Quin, 1996).

Reconstruction

Table 10 lists the original non-volant mammal fauna of the study area as best we can re-construct it, taking account of recent sub-fossil records (Baynes, 1990; Baynes and Jones, 1993; Appendix 2).

Combined, these live and sub-fossil records indicate that 22 mammal species have become extinct in the mainland part of the study area since the time of European settlement (*Bettongia penicillata, Onychogalea lunata, Macrotis lagotis, Chaeropus ecaudatus, Isoodon auratus, I. obesulus, Parantechinus apicalis, Phascogale calura, Leggadina foresti, Notomys amplus, N. longicaudatus, Pseudomys desertor, P. nanus, P. shortridgei, Zyzomys pedunculatus, Leporillus apicalis* and *L. conditor*, as well as the five Shark Bay island species listed below). This is 48% of the original non-volant fauna. The list of extinctions includes dasyurids (two of the original 13 species are extinct), but mainly comprises bandicoots (five of the original five species), macropods (five of 10) and rodents (10 of 16). The overall percentage of extinctions is higher than has been reported for other regions of similar size elsewhere in Australia (see Dickman *et al.*, 1993b; Smith and Quin, 1996; Burbidge and McKenzie, 1989; Baynes and Baird, 1992). For instance, Table 2 in Burbidge and McKenzie (1989) lists 14 of 52 (27%) indigenous non-volant species as extinct in Western Australia's arid pastoral regions, and 16 of 41 (39%) extinct in its deserts. Two species now persist only as isolated populations in the Carnarvon Basin study area (*Petrogale lateralis* and *Rattus tunneyi*) and two others could persist as isolated populations although their original ranges only reached the edges of our study area (*Macropus eugenii* and *Pseudomys chapmani*). There is a significant relationship between extinction and

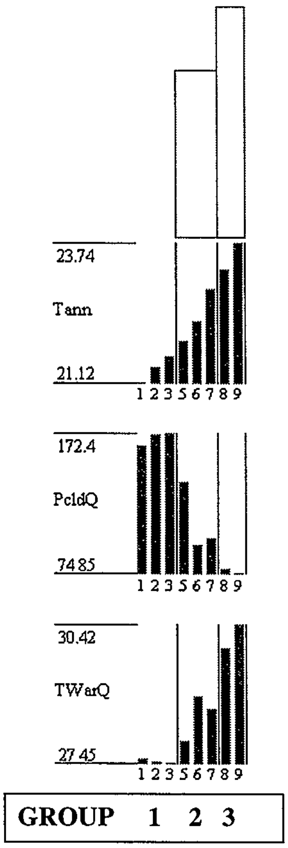


Figure 8 Univariate relationship between sector climatic attributes and patterns in the reconstructed Late Holocene Carnarvon Basin mammal fauna, excluding macropods. The climatic attributes are superimposed as histograms on the dendrogram structure derived by classifying the sectors (numbered 1 to 9 in Figure 1) in terms of similarities in their species composition (Kruskall-Wallis value = 6.3 and P. < 0.044 in each case).

body-size on the mainland part of the study area that points to the importance of continuing to protect Bernier and Dorre Islands. These Shark Bay islands support populations of five of the extinct species (*Bettongia lesueur, Lagostrophus fasciatus, Lagorchestes hirsutus, Perameles bougainville* and *Pseudomys fieldi*, as well as the only population of *Hydromys chrysogaster* from the area. These islands were separated from the mainland during the marine transgression at the beginning of the Holocene (Kendrick *et al.*, 1991), and comprise habitats found in its coastal areas. In contrast, the adjacent mainland's bat fauna appears to be intact (see McKenzie and Muir, 2000).

Shortridge (1910, pp. 818-819) provided an early account of these changes:

- *"Up to quite recently — within the last twenty-five to thirty years ... many of the Western Australian mammals had a much wider range than at the present time, their disappearance, which is said to have been first noticed about 1880, being most sudden and unaccountable. Their former existence is still remembered both by natives and old colonists around Port Hedland, Cossack, Carnarvon, Peak Hill, Laverton, Eucla and many other widely separated localities. The following, and other less easily recognised species, are said to have been very abundant throughout the Western, South-Eastern and Central districts:—* Lagostrophus fasciatus, Lagorchestes hirsutus, Bettongia lesueuri, ..." [Shortridge's Central district is centred on Carnarvon and its western half is Carnarvon Basin study area.]
- *"... they have died out chiefly in the drier parts of the country, where, except for introduction of sheep, there has been little alteration in the natural conditions. Rabbits, although already very numerous in the Central and South-East, have not yet found their way to the North-West."*
- *"While on the island* [Bernier] *during a very dry season, I noticed that both this species* [L. fasciatus] *and* Lagorchestes *were very thin and apparently in a very unhealthy condition, while numbers were lying about dead. It may be noted that sheep have been temporarily introduced there, while in the south of Dirk Hartog there is a large sheep station, and the wallabies are said to have entirely left that end of the island."*

Similar patterns of mammalian extinction have been noted elsewhere in semi-arid and arid areas of Australia since European colonisation (most severe among indigenous, non-flying mammals with a body weight range between 35 g and 5.5 kg — e.g. Burbidge and McKenzie, 1989; Dickman *et al.*, 1993). Shortridge's observations pre-date the appearance of foxes in the study area by more than 20 years and perhaps even rabbits by as much as 10 years (see Table 6), but indicate a mechanism that reduced and/or localised populations of medium-sized indigenous mammals, making them more vulnerable to predation. In relation to mammal extinctions in the Flinders Ranges of South Australia, Tunbridge (1991, p. 21) reached a similar conclusion: *"...on our estimate a considerable number of extinctions had probably occurred prior to its* [the rabbit's] *arrival. The fox arrived too late to be considered the main cause of the demise of most extinct species."*

In combination with the pastorally-managed species (Friedel and James, 1995), the richness, ubiquity and biomass of introduced feral mammals in mainland parts of the study area are matters of concern in terms of the region's ecological sustainability.

Given that the surviving mammals are a biased sub-set of the area's Late-Holocene mammal fauna in terms of both phylogeny and body size, Baynes (1990) suggested that the biogeographical and ecological patterns in the original fauna may have been quite different from those of the surviving elements. However, our analysis shows that the compositional gradients in the re-constructed fauna conform with the same sorts of climatic gradients as do the small ground-dwelling mammal assemblages extant in the study area today (annual average temperature, precipitation in the coldest quarter, and temperature in the warmest quarter — Figure 8 and Table 9). Unfortunately, there are too few data-points to permit a stable analysis of climatic relationships based solely on the extinct component, and insufficient geographical resolution to permit analysis of substrate-driven relationships of the re-constructed fauna.

In the Carnarvon Basin study area, attributes related to temperature, and then soil-texture and rock outcrop, provide the best available basis for reserve selection from the perspective of the non-volant indigenous mammals. For mammals therefore, the reserve system should cover the main soil texture-types in each of the northern, central and southern parts of the study area. Examples of central (MD, WO and eastwards) and north-coastal landscapes are not represented in the existing system.

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Appendix 1

Report by Joan M. Dixon (Senior Curator, Mammalogy, Museum of Victoria) to N.L. McKenzie on the provenance of specimen C9745 (*Pseudomys desertor*).

I have checked the specimen of *Pseudomys desertor* C9745 in the Museum of Victoria collections, and note that it is a 'modern' skin and skull, and not a fossil. The specimen, a female, was collected on Bernier Is. W.A. 26.9.1910, and acquired by the Museum 26.11.1910. A label attached to the skin includes dimensions, and a note by Hill that it was 'Found dead in scrub'. He has also written No. 32 on the tag, apparently his field number.

The colouration and texture of the fur indicates that the specimen is indeed *Pseudomys desertor*.

As Hill's professional career is not given in most bibliographies prior to 1911, I am enclosing appropriate bibliographic details from sources which clearly indicate that he was on Bernier Is. in 1910.

I hope the information sorts out the problem, but if you require further details, please contact me.

Appendix 2

Original mammal faunas of the Carnarvon Basin, based on fossil material from the surfaces of small caves.

by **Alexander Baynes**

Table 1 Fossil mammals from deposits in coastal cliffs in Kalbarri National Park, the study area's south-western extremity (Sector 1 in Fig. 1):
1 = 1.9 km north of Bluff Point (27°50'33"S 114°06'22"E).
2 = 1.9 km north of Bluff Point (27°50'32"S 114°06'23"E).
3 = 2.2 km north of Bluff Point (27°50'22"S 114°06'25"E).
4 = 2.6 km north of Bluff Point (27°50'10"S 114°06'28"E).
5 = 3.0 km north of Bluff Point (27°49'57"S 114°06'30"E).

Species	Site 1	2	3	4	5
Dasycercus cristicauda		x	x		
Parantechinus apicalis		x			
Sminthopsis sp. (*murina* group)		x	x		x
Sminthopsis granulipes		x		x	
Sminthopsis hirtipes		x			
Isoodon obesulus		x			
Perameles bougainville		x	x	x	
Tarsipes rostratus		x	x		
Macroderma gigas				x	
Oryctolagus cuniculus				x	
Leporillus conditor		x			x
Notomys alexis	x	x	x	x	x
Pseudomys albocinereus		x	x	x	x
Pseudomys fieldi		x		x	
Pseudomys hermannsburgensis		x			x
Pseudomys nanus		x			
Pseudomys shortridgei		x	x	x	x
Rattus tunneyi	x	x	x	x	x

Table 2 Fossil mammals ('cf'' = probable record) from deposits on Edel Land (Sector 2 in Fig. 1):

FE — 26°24'S 113°18'E, near False Entrance Well:
M = 'Mosquito Pocket'.
P = 'Promising Cave'.
O = other sites.

Baba — 26°36'S 113°41'E, near Baba Head:
No = Baba Head North.
S = Baba Head South.
Nc = New Cave.

SFC — 26°12'40"S 113°22'23"E, collected from 'salt flat caves' on Heirisson Prong by J. Short.

Species	FE			Baba			SFC
	M	P	O	No	S	Nc	
Tachyglossus aculeatus							x
Dasycercus cristicauda	x	x	x	x	x	x	
Dasyurus geoffroii	x		x		x		x
Parantechinus apicalis	x	x		x	x		
Phascogale calura		x	x	x	x	x	
Sminthopsis dolichura	cf	cf	cf	cf	cf	cf	
Isoodon obesulus		x		x	x	x	
Perameles bougainville	x	x	x	x	x	x	
Bettongia lesueur					x	x	x
Bettongia penicillata							x
Petrogale lateralis	x						
Nyctophilus geoffroyi		x					
Vespadelus finlaysoni		x					
Oryctolagus cuniculus				x	x		
Leporillus apicalis	x	x		x	x	x	x
Leporillus conditor	x	x	x	x	x	x	
Mus musculus		x		x			
Notomys alexis	x	x	x	x	x	x	
Notomys longicaudatus					x		
Pseudomys albocinereus	x	x	x	x		x	
Pseudomys desertor	x	x			x		
Pseudomys fieldi	x	x	x	x	x	x	
Pseudomys hermannsburgensis	x	x	x	x	x	x	
Pseudomys nanus				x	x	x	
Pseudomys shortridgei	x	x	x				
Rattus tunneyi	x	x	x	x	x	x	

Table 3 Fossil mammals ('?' = less certain record) from deposits on the Shark Bay islands (Sectors 3 & 4 in Fig. 1):

DHI = Dirk Hartog Island:
H = Herald Heights, 25°58'S 113°06'E.
W = West Coast Well, 25°45'S 112°57'E.
N = Notch Point, 25°56'S 113°10'E.
DI = Dorre Island.
BI = Bernier Island.

Species		DHI		DI	BI
	H	W	N		
Dasycercus cristicauda	x	x			
Dasyurus geoffroii		x	x		
Parantechinus apicalis	x				
Sminthopsis dolichura	x	x			
Perameles bougainville	x	x	x	x	x
Bettongia lesueur	x		x	x	x
Bettongia penicillata	x				
Lagorchestes hirsutus				x	x
Lagostrophus fasciatus				x	x
Nyctophilus geoffroyi		x			
Leporillus conditor	x	x			
Pseudomys albocinereus	?			x	x
Pseudomys desertor	x				x
Pseudomys fieldi	x	x	x		x
Pseudomys hermannsburgensis	x	x			
Pseudomys shortridgei	x	x			

Table 4 Fossil mammals (cf = probable record) from deposits on Peron Peninsula (Sector 5, Fig. 1):

HB = Herald Bluff:
1 = 25°38'26"S 113°34'38"E, 1.1 km WNW of Herald Bluff.
2 = 25°38'35"S 113°35'05"E, 0.3 km NW of Herald Bluff.
3 = several very small cavities between sites 1 and 2.
MM = archaeological excavations in two small rockshelters at Monkey Mia (Bowdler 1995).
FI = Faure Island.

Species		HB		MM	FI
	1	2	3		
Tachyglossus aculeatus			x		
Dasycercus cristicauda		x			
Dasyurus geoffroii		x			
Phascogale calura		x			
Sminthopsis dolichura		cf			
Perameles bougainville	x	x			
Bettongia penicillata		x	x		x
Lagorchestes hirsutus		x			
Lagostrophus fasciatus				x	
Onychogalea lunata	x	x	x	x	
Oryctolagus cuniculus			x	x	
Leporillus apicalis	x	x	x	x	
Leporillus conditor		x		x	
Notomys alexis		x	x	x	
Pseudomys fieldi		x			
Pseudomys hermannsburgensis		x			
Rattus tunneyi		x			

Table 5 Fossil mammals (? = less certain record) from deposits in north-western coastal areas (Sector 7, Fig. 1), mostly from small caves in coastal cliffs:

1. 3.0 km ENE Cape Cuvier, 24°13'05"S 113°25'00"E (ABRS 121/1).
2. 11.2 km NNE of Cape Cuvier, 24°08'06"S 113°26'27"E (N.J.H. Cave 1).
3. Side pocket of N.J.H. Cave 1.
4. 11.5 km NNE of Cape Cuvier 24°07'54"S 113°26'12"E (N.J.H. Cave 2).
5. 12.7 km NE of Cape Cuvier 24°07'09"S 113°26'05"E (ABRS 121/2).
6. 13.0 km NE of Cape Cuvier 24°06'56"S 113°25'59"E (0.4 km N of ABRS 121/2).
7. 13.3 km NE of Cape Cuvier 24°05'59"S 113°25'55"E (0.75 km N of ABRS 121/2).
8. Breakaway 0.8 km SE of Cardabia homestead, 23°06'34"S 113°48'29"E.
9. Breakaway 0.8 km E of Cardabia homestead, 23°06'34"S 113°48'29"E.
10. 4.4 km S. of Point Maud, 23°09'47"S 113°45'52"E.

Species	1	2	3	4	5	6	7	8	9	10
Tachyglossus aculeatus										x
Dasycercus cristicauda		x		x		x	x			
Dasyurus geoffroii										x
Phascogale calura					x					
Sminthopsis hirtipes		x		x		x				
Sminthopsis youngsoni	x			x		x				
Isoodon sp.	x			x	x	x	x	x		
Perameles bougainville							x	x		
Bettongia lesueur			x							
Bettongia sp. indet.					x					
Macropus robustus					x					
Oryctolagus cuniculus					x			x		
Leporillus apicalis						x		x		
Leporillus conditor			x	x	x	x	x	x	x	
Mus musculus	x			x	x	x			x	
Notomys alexis	?	x	x	x			x	x	x	
Notomys amplus	?			x		x	x	?	x	
Pseudomys albocinereus	x	x	x	x		x	x			
Pseudomys desertor	x	x		x		x		x		
Pseudomys fieldi	x	x		x	x	x	x	x		
Pseudomys hermannsburgensis	x			x	x	x		x		
Rattus tunneyi	x	x	x	x	x	x	x	x	x	x

Table 6 Fossil mammals (? = less certain record) from three deposits in the Carbla Plateau area near Yaringa lookout (25°59'S 114°17'E) (Sector 6 in Fig. 1):

Species	1	3	4
Antechinomys laniger	?	x	x
Dasycercus cristicauda	x	x	x
Dasyurus geoffroii		x	
Phascogale calura		x	x
Sminthopsis dolichura	?		
Sminthopsis macroura		x	
Chaeropus ecaudatus	x	x	x
Isoodon auratus	x	x	x
Perameles bougainville	x	x	x
Macrotis lagotis	x	x	
Macropus robustus			?
Leporillus apicalis	x	x	x
Leporillus conditor	x	x	x
Notomys alexis	x	x	x
Notomys longicaudatus	x	x	x
Pseudomys fieldi	x	x	x
Pseudomys hermannsburgensis	x	x	x
Pseudomys nanus	x	x	x
Rattus tunneyi	x	x	x

Table 7 Fossil mammals (? = less certain record) from deposits in the central-eastern part of the study area (Sector 8, Figure 1):
Wi = Winderie, 25°21'15"S 115°08'38"E.
TT = Mesa near Tabletop Well: sites 1 and 2 at 24°45'48"S 115°21'18"E.
PR = Pells Range:
N.J.H. site 1, 2 km NW of Pells Creek Crossing 25°12'30"S 115°29'30"E.
N.J.H. site 2, 3 km NW of Pells Creek Crossing 25°12'24"S 115°29'25"E.

Species	Wi	TT	PR		
		1	2	1	2
Dasycercus cristicauda	x	x	x		
Phascogale calura	x	x	x		
Dasykaluta rosamondae		?			
Antechinomys laniger		x	x		
Sminthopsis macroura		?	?		
Chaeropus ecaudatus	x	x	x		
Isoodon auratus	x	x	x		
Perameles bougainville	x	x			
Macrotis lagotis				x	
Leggadina forresti		x			
Leporillus apicalis	x	x	x		?
Mus musculus	x	x	x		
Notomys alexis	x	x	x	x	
Notomys amplus	x	x	x	x	
Notomys longicaudatus	x	x	x	x	
Pseudomys fieldi	x	x	x	x	
Pseudomys hermannsburgensis	x	x	x	x	
Pseudomys nanus	x	x	x	x	
Rattus tunneyi	x	x	x	x	
Zyzomys pedunculatus	x	x			

Table 8 Fossil mammals from a cleft in the sandstone bluff on the southern bank of the Minilya River at 23°51'39"S 115°09'13"E near Williambury (WI). This site is in the inland northern part of the study area (Sector 9, Figure:

Species	WI
Dasycercus cristicauda	x
Notomys alexis	x
Notomys amplus	x
Notomys longicaudatus	x
Pseudomys fieldi	x
Pseudomys hermannsburgensis	x
Pseudomys nanus	x
Rattus tunneyi	x
Zyzomys sp.	x