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# Small mammal and reptile assemblages of the semi-arid woodlands and *Acacia* sandplains in the southern rangelands of Western Australia

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## ABSTRACT

As part of a broader study involving the control of introduced predators, the seasonal abundance of small vertebrate fauna was monitored in winter and spring during 2006 and 2007 at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in the Avon–Wheatbelt and Yalgoo bioregions in Western Australia. Ten small mammal, 30 reptile and three amphibian species were recorded at 24 sites within each of four land system types represented at both sites. The most-often recorded species of small mammal were *Mus musculus*, *Pseudomys hermannsburgensis*, *Notomys mitchelli, Sminthopsis dolichura* and *S. crassicaudata*, and of reptile were *Ctenotus mimetes* and *C. schomburgkii.* Species richness was greatest within the Euchre land system at Mt Gibson, characterized by low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands. At Karara–Lochada species richness was greatest within the Pindar land system, characterized by red loamy sandplain supporting similar vegetation assemblages. Twenty-three of the total 43 small mammal, reptile and amphibian species were present at both sites, while 13 occurred only at Mt Gibson and seven only at Karara–Lochada. Faunal assemblage structure was different between stations, land systems and years. Over 50% of the difference in faunal assemblage structure was accounted for by six species: *N. mitchelli*, *S. dolichura* and *C. mimetes* (more abundant at Mt Gibson) and *C. schomburgkii*, *P. hermannsburgensis* and *M. musculus* (more abundant at Karara–Lochada). These same six species were also responsible for 52% of the difference in faunal assemblage structure between years. There was a general decline in small mammal and reptile abundance at the two stations in the second year of monitoring.

Keywords: mammals, rangelands, reptiles, trapping survey.

## INTRODUCTION

The Australian Wildlife Conservancy (AWC) and Department of Environment and Conservation (DEC), in partnership with the Invasive Animals Co-operative Research Centre (IA CRC), commenced a project in 2006 to investigate techniques for the sustained control of introduced predators in the southern rangelands of Western Australia, with an emphasis on controlling feral cats (Richards & Algar 2008). At the treatment site, AWC's Mt Gibson Wildlife Sanctuary, a strategy for the control of introduced predators was implemented, and at the control site, DEC's Karara–Lochada Pastoral Station—in close proximity and with a similar suite of land system types—introduced predators were not controlled.



As part of the broader project to control the feral cat (*Felis catus*), fox (*Vulpes vulpes*) and wild dog (*Canis familiaris*) trio, the abundance of their prey items (small mammals, reptiles, birds and invertebrates) was monitored within the semi-arid *Eucalyptus* woodlands and sandplains dominated by *Acacia* shrublands on the two stations. These vegetation types characterize the semi-arid southern rangelands to the north of the wheatbelt zone in Western Australia. Other results of the broader project will be reported elsewhere, including papers within the same volume of this journal.

The small mammal and reptile fauna in the region has been documented in a number of unpublished, small-scale surveys conducted in association with mining companies (and other organizations such as DEC, AWC and Bush Heritage Australia) for particular reserves within the region and surrounding areas. In particular, information on small mammal and reptile species assemblages has been provided by DEC for areas to the north (Carnarvon Basin; Burbidge et al. 2000; McKenzie 2000; McKenzie et al. 2000), east (Goldfields; Burbidge et al. 1995), south (Wheatbelt; Burbidge et al. 2004; Kitchener et al. 1980a, 1980b) and west (Burbidge et al. 1989).

In this paper we document the small mammal and reptile species assemblages at 24 sites sampled in the two study areas (Mt Gibson and Karara–Lochada) within the semi-arid southern rangelands immediately to the north of the wheatbelt zone in Western Australia. We describe how the composition of these assemblages varies across land system types within and between the properties, and potential impacts of variation in rainfall.

## METHODS

### Mt Gibson Wildlife Sanctuary Study Site

Mt Gibson Wildlife Sanctuary is located approximately halfway between Wubin and Paynes Find in Western Australia (29º 36' 36.2" S, 117º 24' 31.3" E), and covers an area of 130,500 ha, straddling the boundary between the South-West and Eremaean Botanical Provinces (Fig. 1). The area has a semi-arid climate with hot dry summers and mild wet winters. Summer temperatures range between 19–36 °C (minimum–maximum), and winter temperatures between 6–18 °C. There are typically 9–11 months of predominantly dry weather, with an annual rainfall of 343 mm. Evapotranspiration rates are considerably higher than rainfall, with the annual average for the Paynes Find region being 2,480 mm.

Mt Gibson is characterized by mixed *Acacia* shrublands on sandplain and York Gum (*Eucalyptus loxophleba*), Salmon Gum (*E. salmonophloia*) and Gimlet (*E. salubris*) woodlands. The sanctuary contains 13 vegetation associations (Beard 1976). The dominant landforms are greenstone ranges in the north-east and banded ironstone formations to the north-west. Granites and gneisses of the Yilgarn Block underlie much of the area and outcrop as domes or breakaways (McKenzie & May 2003). The ranges are separated by gently sloping pediments and floodplains upslope from salt lakes and clay pans (McKenzie & May 2003). Sandplains occur extensively to the south. Drainage is internal and disorganized and an extensive salt lake, Lake Moore, bounds Mt Gibson Wildlife Sanctuary to the east.

The conservation organization AWC acquired the Mt Gibson pastoral lease, which had been managed conservatively for the preceding 20 years to promote environmental values, in 2001. The lease was subsequently destocked, removing most sheep (*Ovis aries*) and goats (*Capra hircus*). Fox control was conducted in 2004 and 2005 by AWC using 1080 dried meat baits laid by hand throughout the sanctuary. Prior to this, minimal predator control activities had been conducted by neighbouring pastoral lessees in an ad hoc manner and mostly directed towards baiting of wild dogs. Mt Gibson was chosen as a 'treatment' site in the predator control project, where introduced predators were controlled with an annual aerial baiting of 70,000 'Eradicat' baits over the entire pastoral lease in July 2006 and August 2007 (Richards & Algar 2008).

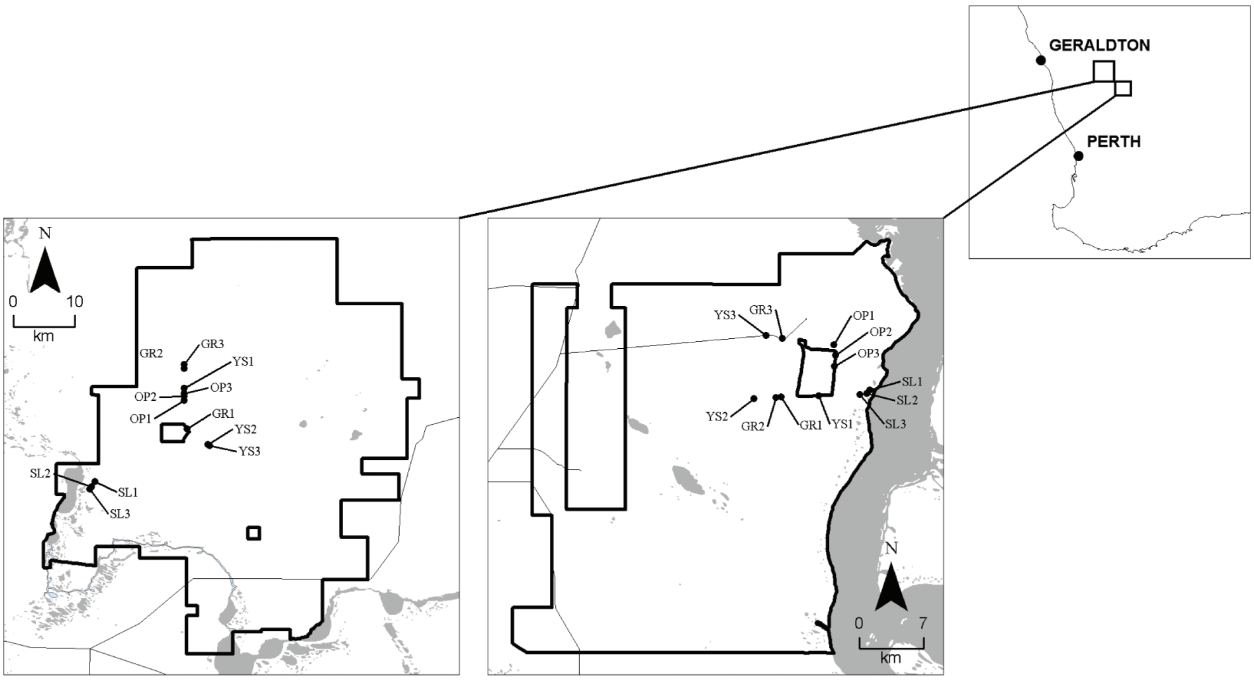


*Figure 1. Location of Karara–Lochada Pastoral Station (left) and Mt Gibson Wildlife Sanctuary (right) in the southern rangelands region of Western Australia and the 24 quadrats described in this study.*

## Karara–Lochada Study Site

Karara (29° 14' 21" S, 116° 43' 44" E) and Lochada (29° 12' 60" S, 116° 33' 60" E) are adjacent pastoral stations managed by DEC and are located 86 km north of Mt Gibson Wildlife Sanctuary and 50 km east of Morawa. They cover an area of 109,300 ha and 114,600 ha respectively (Fig. 1). The average annual rainfall recorded for Karara is 312 mm (Bureau of Meteorology; based on records 1928–1939 and 1992–2008) and for Lochada is 327 mm (Bureau of Meteorology; based on records 1911–1939).

The climate, landforms, land systems and vegetation associations within the Karara–Lochada pastoral leases are similar to those found on Mt Gibson. Karara–Lochada also lies on the interface between the South West Botanical Province and the Eremaean Botanical Province, and mainly lies within the Yalgoo bioregion. There are at least 14 land types (Van Vreeswyk & Godden 1998) and 14 vegetation types (Beard 1976) on Karara. The area is characterized by mixed *Acacia* shrublands on sandplain and sparse York Gum woodlands. The stations lie within the Yilgarn craton and across the boundaries of the Murchison Plateau and the Salinaland Plateau, with frequent granite rises and low domes.

The pastoral leases have historically run Merino sheep, and feral goats have been mustered and sold in recent years. The properties were purchased by DEC in 2000 and 2002 and subsequently destocked for conservation purposes. Karara–Lochada was chosen as the 'control' site, where introduced predators were not baited. Minimal predator control had been conducted on the pastoral leases prior to this study, and was mostly undertaken by neighbouring pastoral lessees in an ad hoc manner to bait wild dogs.

## Small Mammal and Reptile Trapping Surveys

Twelve sites were selected at each property, three within each of four 'land system' types (Department of Agriculture and Food Western Australia 1990) characteristic of both Karara–Lochada and Mount Gibson: 1) Joseph (YS; yellow sandplains)—undulating yellow sandplains supporting dense mixed *Acacia* shrublands on yellow sandplain; 2) Pindar (OP; Olympic plains)—red loamy sandplain supporting *Eucalyptus* woodlands and *Acacia* shrublands; 3) Euchre (GR; granite)—low granite breakaways with alluvial plains and sandy tracts supporting *Eucalyptus* woodlands and *Acacia* shrublands with patchy mallees on granitic breakaways; and 4) Carnegie (SL; salt lake)—salt lakes with fringing saline plains, dunes and sandy banks. Each site was approximately 1.6 ha, at least 0.5 km apart and adjacent to vehicle tracks for easy access (Fig. 1).

Surveys were conducted twice each year for two years: in winter (20–24 June 2006, 11–15 July 2007 at Mt Gibson and 26–30 June 2006, 6–10 July 2007 at Karara–Lochada), just prior to aerial predator baiting to assess potential prey abundance at its lowest; and in spring (25–29 September 2006, 3–7 October 2007 at Mt Gibson and 19–23 September 2006, 23–27 September 2007 at Karara–Lochada), when populations had potentially commenced receiving an influx of small mammal recruits after breeding. Each site was sampled using 25 pitfall traps (20 l plastic bucket with 7 m of wire mesh drift fence) and 25 Elliott traps (baited with universal bait of rolled oats, peanut butter and sardines). One pitfall trap and one Elliott trap were placed at each station (five rows 50 m apart with traps spaced at 20 m intervals along each row). All animals captured were marked with non-toxic paint, weighed and measured before release at the capture location. Recaptures were recorded and released with no additional measurements taken. Pitfall traps were open continuously for four nights and checked early each following morning. Elliott traps were baited each afternoon and checked early the following morning. Elliott traps were re-checked in the afternoon during warmer weather whilst re-baiting however no animals were captured during the day in any survey.

## Statistical Analyses

All captures at each site within each year were combined into a species by site matrix for each year. These data were analyzed by a permutational multivariate repeated measures analysis of variance (PERMANOVA) using the PERMANOVA+ add-on to the PRIMER-E software package (Anderson et al. 2008). There were two fixed, orthogonal, between-site factors:

- station (two levels—Mt Gibson (MG) and Karara–Lochada (KL)),
- land system (four levels—YS, OP, GR and SL);

and one fixed, within-site factor:

- year (two levels—2006 and 2007).

All data were square-root transformed prior to analysis to ensure that similarity values were not dominated by a few highly abundant species (Clarke & Warwick 2001) and pairwise similarities between all sites were estimated by the Bray-Curtis similarity coefficient. Post-hoc comparisons between levels of factors were performed by PERMANOVA, using Monte Carlo sampling to generate probability levels as the number of unique permutations for each pairwise test were too low (Anderson et al. 2008).

Canonical Analysis of Principal Coordinates, or CAP analysis (Anderson & Willis 2003) was used to find the axes best capable of discriminating between both the station – land system and the station–year combinations of sites. The position of sites on these axes was overlayed with species vectors, indicating the strength and the direction of the Spearman rank correlation between those species and the CAP axes (Anderson et al. 2008). The identity of the species contributing the most to the separation of levels within significant factors was determined with the SIMPER routine within PRIMER-E.

# RESULTS

## Small Mammal and Reptile Trapping Surveys

Ten small mammal species (nine native, one introduced) were recorded at the 24 trapping sites distributed between Mt Gibson and Karara–Lochada Pastoral Stations in the four trapping sessions in 2006 and 2007 (Table 1). The introduced house mouse (*Mus musculus*) was captured at both sites. Seven native mammal species were captured at Mt Gibson and eight at Karara–Lochada, of which six species were captured at both sites. *Antechinomys laniger* was captured only at Karara–Lochada and *Ningaui yvonnae* and *Sminthopsis gilberti* only at Mt Gibson, however, all were single captures only.

The most commonly trapped small mammals were *Notomys mitchelli*, *S. dolichura*, *M. musculus* and *Pseudomys hermannsburgensis* at Mt Gibson, and *M. musculus* and *P. hermannsburgensis* at Karara–Lochada (Table 1). Small mammals were nearly twice as abundant at Mt Gibson than at Karara–Lochada. The average number of species trapped at each of the 24 sites was 9.8 (range 6–14).

Thirty reptile and three amphibian species were recorded at the 24 sites distributed between Mt Gibson and Karara–Lochada Pastoral Stations during the four trapping sessions (Table 1). Twenty-seven of these species were captured at Mt Gibson and 22 at Karara–Lochada, of which 16 species were captured at both sites. Of the 17 species captured at one property only, 12 were single captures and two were captures of two. *Gehyra variegata* was common at Mt Gibson (10 captures), but was not captured at Karara–Lochada, and *Strophurus assimilus*

**Table 1**

Total number of mammal, reptile and amphibian species trapped during the four survey periods.

| Taxon | Species | Mt Gibson | Karara–Lochada |
|---|---|---|---|
| Mammals | *Antechinomys laniger* | – | 1 |
| | *Mus musculus* | 47 | 69 |
| | *Ningaui yvonneae* | 1 | – |
| | *Notomys alexis* | 2 | 1 |
| | *Notomys mitchelli* | 99 | 9 |
| | *Pseudomys hermannsburgensis* | 41 | 68 |
| | *Sminthopsis crassicaudata* | 14 | 4 |
| | *Sminthopsis dolichura* | 97 | 9 |
| | *Sminthopsis gilberti* | 1 | – |
| | *Sminthopsis* sp. | – | 4 |
| | | **302 (8 species)** | **161 (8 species)** |
| Reptiles | *Brachyurophis semifasciata* | 2 | – |
| | *Caimanops amphiboluroides* | – | 1 |
| | *Cryptoblepharus buchanani* | 2 | 1 |
| | *Ctenophorus cristatus* | 1 | – |
| | *Ctenophorus reticulatus* | 5 | 9 |
| | *Ctenophorus scutulatus* | 19 | 7 |
| | *Ctenotus mimetes* | 93 | 37 |
| | *Ctenotus pantherinus* | 7 | 2 |
| | *Ctenotus schomburgkii* | 48 | 73 |
| | *Ctenotus uber* | – | 1 |
| | *Diplodactylus granariensis* | 4 | 15 |
| | *Diplodactylus intermedius* | 2 | – |
| | *Diplodactylus pulcher* | 8 | 17 |
| | *Gehyra variegata* | 10 | – |
| | *Heteronotia binoei* | 1 | 1 |
| | *Lerista gerrardii* | – | 1 |
| | *Lerista muelleri complex* | 2 | 3 |
| | *Lerista nichollsi?* | – | 1 |
| | *Lialis burtonis* | 1 | – |
| | *Liopholis inornata* | 1 | 10 |
| | *Lucasium squarrosum* | 3 | 6 |
| | *Menetia greyii* | 5 | 11 |
| | *Nephrurus vertebralis* | 1 | – |
| | *Pogona minor* | 12 | 7 |
| | *Rhynchoedura ornata* | 1 | – |
| | *Strophurus assimilus* | 4 | – |
| | *Suta fasciata* | 1 | – |
| | *Tiliqua occipitalis* | – | 1 |
| | *Varanus caudilineatus* | 11 | 1 |
| | *Varanus gouldii* | 1 | – |
| | | **245 (25 species)** | **205 (20 species)** |
| Amphibians | *Neobatrachus pelabatoides* | 5 | 1 |
| | *Neobatrachus sp.* | – | 4 |
| | *Pseudophryne occidentalis* | 1 | – |
| | | **6 (2 species)** | **5 (2 species)** |

was captured four times at Mt Gibson but was not captured at Karara–Lochada. These species are likely to be present at both locations. Frogs were not targeted as part of the survey and were therefore rarely captured due to a lack of rainfall events during the four survey periods. Four *Neobatrachus* sp. were captured at Karara–Lochada and were unable to be identified, though were likely to be either *N. centralis*, *N. sutor* or *N. kunapalari*.

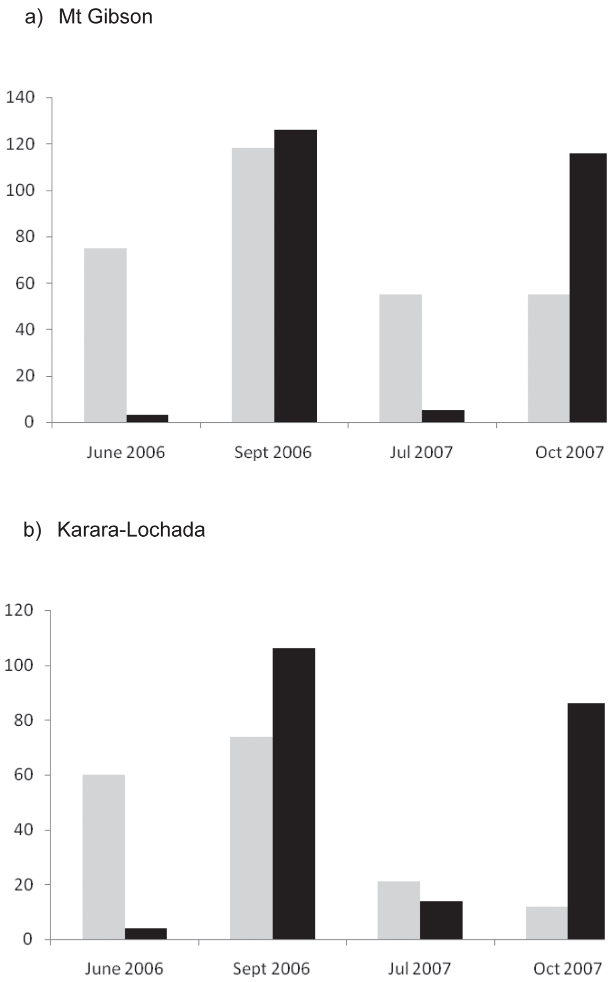


*Figure 2. Number of small mammals (pale grey) and reptiles and amphibians (black) captured at: a) Mt Gibson and b) Karara–Lochada in 2006 and 2007.*

The majority of reptiles were captured during the spring surveys (Fig. 2). Only two reptiles were captured in the two winter surveys at Mt Gibson and 13 at Karara–Lochada. As with mammals, the number of reptile captures was slightly higher at Mt Gibson than Karara–Lochada during the spring surveys and also appeared to decline from 2006 to 2007 at both stations.

During the two-year study period, Mt Gibson received an annual rainfall of 341 mm in 2006 and only 264 mm in 2007; the latter below the average annual rainfall of 343 mm and one of the lowest since recording commenced (Bureau of Meteorology records 1983 to 2007). Karara received an annual rainfall of 392 mm in 2006, and 196 mm in 2007; the latter also substantially below the average annual rainfall of 312 mm (Bureau of Meteorology records; based on records 1928–1939 and 1992–2008).

The land system type with the most abundant captures of small mammals, reptiles and amphibians over the four combined survey periods was GR at Mt Gibson and OP at Karara–Lochada (Table 2). The most abundant mammal and reptile species were captured across all four land system types. Overall, the average number of species per site trapped within the four land system types was highest in SL.

## Statistical Analyses

Faunal assemblage structure was shown to be significantly different between stations, land systems and years (Table 3). There were also significant interactions between stations and land systems and stations and year. Pairwise

**Table 2**

Percentage of small mammal, reptile and amphibian captures over the four survey periods and the average number of species captured per site.

| Land system | Mt Gibson | Karara–Lochada | Average # of species per site |
|---|---|---|---|
| Euchre (GR) | 30.9% of 533 captures | 18.8% of 377 captures | 9.8 |
| Pindar (OP) | 23.7 | 40.0 | 10.2 |
| Joseph (YS) | 23.2 | 19.1 | 8.7 |
| Carnegie (SL) | 22.2 | 22.0 | 10.3 |

**Table 3**

Results of the PERMANOVA of the effect of station, land system and year on the structure of faunal assemblages at Mt Gibson and Karara–Lochada.

| Source | df | Mean Square | Pseudo-F | p | # permutations |
|---|---|---|---|---|---|
| Station | 1 | 12290.0 | 6.9376 | *0.0002* | 4980 |
| Landsystem | 3 | 9793.8 | 5.5284 | *0.0002* | 4981 |
| Station x landsystem | 3 | 3395.7 | 1.9168 | *0.0076* | 4974 |
| Site (station x landsystem) | 16 | 1771.6 | | | |
| Year | 1 | 9721.9 | 9.8269 | *0.0002* | 4984 |
| Station x year | 1 | 2609.4 | 2.6376 | *0.0282* | 4985 |
| Landsystem x year | 3 | 1173.0 | 1.1857 | 0.3030 | 4980 |
| Station x landsystem x year | 3 | 1378.8 | 1.3937 | 0.1748 | 4978 |
| Residual | 16 | 989.3 | | | |

**Table 4**

The abundances and contribution to separation of the assemblages at the two stations, Mt Gibson (MG) and Karara–Lochada (KL). Note: abundances are given as untransformed means across sites, while contribution to dissimilarity is based on the Bray-Curtis similarity indices, calculated on square-root transformed data.

| Species | Average abundance at sites at MG | Average abundance at sites at KL | Contribution to dissimilarity |
|---|---|---|---|
| *Notomys mitchelli* | 4.13 | 0.38 | 11.45% |
| *Sminthopsis dolichura* | 3.88 | 1.58 | 10.37% |
| *Ctenotus mimetes* | 3.88 | 0.42 | 9.29% |
| *Ctenotus schomburgkii* | 2.00 | 3.04 | 8.88% |
| *Pseudomys hermannsburgensis* | 1.63 | 2.83 | 7.78% |
| *Mus musculus* | 2.04 | 2.88 | 5.83% |
| Total contribution | | | 53.60% |

**Table 5**

The abundances and contribution to separation of the assemblages in the two years, 2006 and 2007. Note: abundances are given as untransformed means across sites, while contribution to dissimilarity is based on the Bray-Curtis similarity indices, calculated on square-root transformed data.

| Species | Average abundance at all sites in 2006 | Average abundance at all sites in 2007 | Contribution to dissimilarity |
|---|---|---|---|
| *Mus musculus* | 4.25 | 0.67 | 12.45% |
| *Ctenotus mimetes* | 3.63 | 1.83 | 9.20% |
| *Ctenotus schomburgkii* | 2.21 | 2.83 | 9.12% |
| *Pseudomys hermannsburgensis* | 2.96 | 1.50 | 8.61% |
| *Notomys mitchelli* | 2.38 | 2.13 | 6.36% |
| *Sminthopsis dolichura* | 3.00 | 1.29 | 6.35% |
| Total contribution | | | 52.10% |

post-hoc comparisons of stations within land systems showed significant differences in assemblage structure between the GP landsystems at Mt Gibson and Karara–Lochada ($p = 0.007$) and between the OP landsystems at Mt Gibson and Karara–Lochada ($p = 0.019$). There was no difference in the other two land systems across stations. Pairwise post-hoc comparisons of land systems within stations showed significant differences ($0.01 < p < 0.05$) between all land systems except OP and YS, and YS and GR, at Mt Gibson, and between all land systems except OP and YS, and GR and SL, at Karara–Lochada ($p < 0.01$ for GR v OP and $0.01 < p < 0.05$ for SL v YS, SL v OP and GR v YS).

Pairwise post-hoc comparisons of stations within years showed assemblages at Mt Gibson and Karara–Lochada to be different in both years (p(perm) = 0.0002 and 0.0004 based on 4983 and 4987 permutations, respectively). Similarly, assemblages recorded in 2006 and 2007 were different at both Mt Gibson and Karara–Lochada (p(perm) = 0.005 and 0.002 based on 4986 and 4987 permutations respectively).

Over 50% of the difference in faunal assemblage structure at Mt Gibson and Karara–Lochada was accounted for by six species: *Notomys mitchelli*, *Sminthopsis dolichura* and *Ctenotus mimetes* (all noticeably more abundant at Mt Gibson; Tables 1 and 4) and *C. schomburgkii*, *Pseudomys hermannsburgensis* and *M.musculus* (all more abundant at Karara–Lochada; Tables 1 and 4). These same six species were also responsible for 52% of the difference in faunal assemblage structure between years, with the four mammal species and *C. mimetes* decreasing in abundance from 2006 to 2007, and *C. schomburgkii* increasing in abundance (Table 5).

The high numbers of *C. mimetes* in the GR land system linked the GR sites and distinguished them from those in other land systems (Table 6). *C. schomburgkii* and *P. hermannsburgensis* were common at OP sites, the former contributing most to the difference between OP and SL sites, and both contributing to the difference

**Table 6**

Average similarity of the assemblages within and between land systems. For each pairwise comparison, the species contributing the most to the **similarity** of sites within land systems (diagonal) or the **differentiation** of sites between land systems (off-diagonal) are given. Percentages are the similarity between each land system pair. Species in bold indicate they are at a greater abundance in the land system heading the column.

| | GR | YS | OP | SL |
|---|---|---|---|---|
| GR | 35.8%<br>*C. mimetes* | | | |
| YS | 20.0%<br>***C. mimetes***<br>*N. mitchelli*<br>*C. schomburgkii* | 32.8%<br>*C. schomburgkii*<br>*N. mitchelli* | | |
| OP | 19.1%<br>***C. mimetes***<br>*C. schomburgkii* | 30.9%<br>*C. schomburgkii*<br>***N. mitchelli***<br>*Pseudomys* | 33.4%<br>*C. schomburgkii*<br>*Pseudomys* | |
| SL | 31.3%<br>***C. minetes***<br>*Pseudomys*<br>*S. dolichura* | 18.3%<br>***N. mitchelli***<br>*Pseudomys*<br>*C. schomburgkii*<br>*C. mimetes* | 22.8%<br>***C. schomburgkii***<br>*Pseudomys*<br>***M. musculus*** | 36.2%<br>*Pseudomys*<br>*C. minetes* |

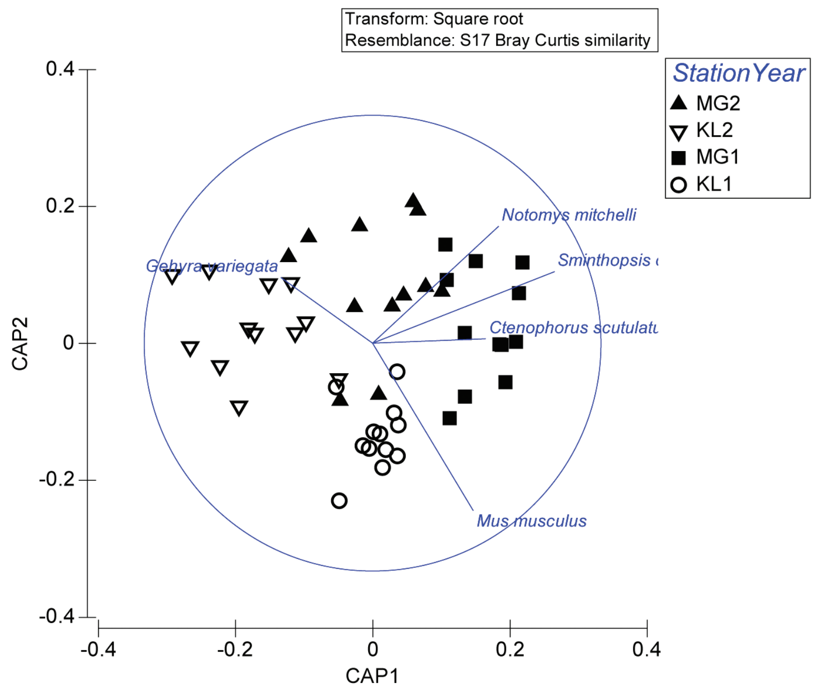


*Figure 3. Separation of sites by station and year by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations with the CAP axes. MG: Mt Gibson, KL: Karara-Lochada pastoral stations; 1: 2006, 2: 2007.* Sminthopsis = Sminthopsis dolichura

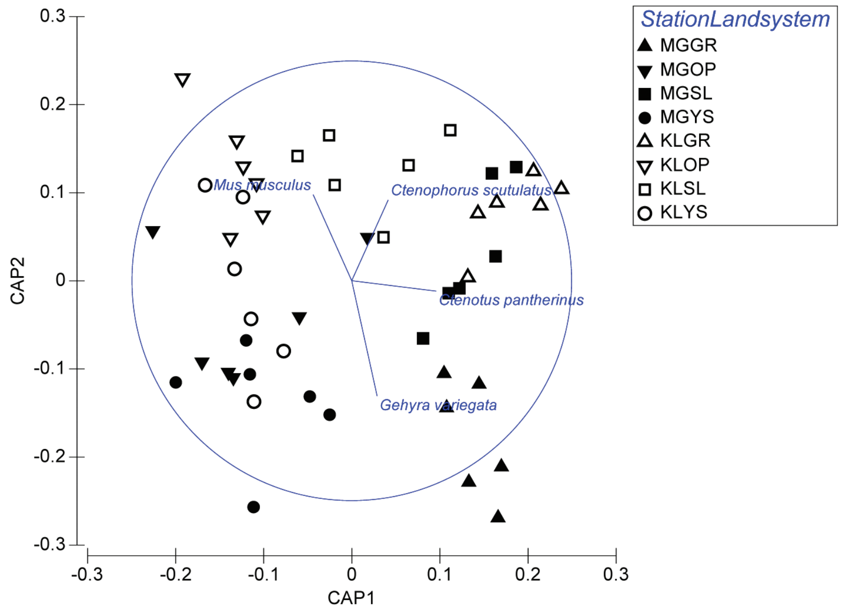


*Figure 4. Separation of sites by station and land system by Canonical Analysis of Principal Coordinates. Vectors show the direction of the contribution of some of the species with the highest Spearman rank correlations with the CAP axes. MG: Mt Gibson, KL: Karara–Lochada pastoral stations; GR: Euchre, OP: Pindar, SL: Carnegie, YS: Joseph landsystems.*

between OP and YS sites. SL sites were linked by higher abundances of *P. hermannsbergensis*, which contributed to the difference between those sites and sites in the other three land systems, while YS sites were linked by higher numbers of *C. schomburgkii* and *N. mitchelli* and these both contributed to the difference between YS and GR sites, with *N. mitchelli* contributing to the difference between YS and all other sites.

Stations and years separated on the first two CAP axes (Fig. 3). Based on 10 principal coordinate axes, CAP correctly classified 73% of the sites into their station–year groups. This was highly significant, with a trace statistic of 1.645 ($p = 0.0002$). Increasing numbers of *S. dolichura*, *S. crassicaudata*, *Ctenophorus scutulatus* and *N. mitchelli* were positively correlated with the CAP1 axis, while decreases in *M. musculus*, *P. hermannsburgensis*, *Lucasium squarrosum* and increases in *N. mitchelli, S. dolichura* and *G. variegata* correlated with the CAP2 axis.

Separation of stations and land systems was less clear (Fig. 4), with only 56% of the sites correctly classified into their station – land system groups, based on seven axes. However, this was also highly significant (trace statistic of 2.586, p = 0.0002). Increasing numbers of *Ctenotus pantherinus* and *Ctenophorus scutulatus* were positively correlated with the CAP1 axis, while decreases in *G. variegata* and increases in *M. musculus, C. scutulatus* and *S. crassicaudata* correlated with the CAP2 axis.

## DISCUSSION

### Faunal Assemblages of Mt Gibson and Karara–Lochada

The Mt Gibson and Karara–Lochada region possesses elements of both the South-West and Eremaean Botanical Provinces, with a blend of south-west and arid zone vegetation assemblages characteristic of the Yalgoo, Avon Wheatbelt and Murchison IBRA bioregions, and their associated faunal species. Ten small mammal, 30 reptile and three amphibian species were recorded at Mt Gibson Wildlife Sanctuary and Karara–Lochada Pastoral Stations in 2006 and 2007 over four survey periods.

The most-often recorded species of small mammal trapped at the two stations were similar, despite some variation between the four land system types and the two years surveyed. The ubiquitous introduced house mouse (*M. musculus*), the sandy inland mouse (*P. hermannsburgensis*), Mitchell's hopping-mouse (*N. mitchelli*), the little long-tailed dunnart (*S. dolichura*) and fat-tailed dunnart (*S. crassicaudata*) were the most common small mammals captured at both Mt Gibson and Karara–Lochada. It is interesting to note that *M. musculus* and the suite of small native mammals occurred together within each of the land systems at varying abundances, considering the suggestion that *M. musculus* may compete with other small granivores and insectivores or be potential predators of small reptiles (Burbidge et al. 2004; Cuthbert & Hilton 2004). The presence of introduced *M. musculus* did not significantly affect resident small mammal or reptile abundance during a six-year study at the Arid Recovery Reserve in South Australia (Moseby et al. 2009).

Other species trapped rarely included the spinifex hopping-mouse (*N. alexis*), Gilbert's dunnart (*S. gilberti*), the kultarr (*A. laniger*) and the southern ningaui (*N. yvonnae*), all of which were recorded at only one of the two stations. Based upon both the extant mammal fauna and original mammal fauna collected from remains at Mt Gibson (Baynes 2002), the region is regarded as representative of both the dry south-west and arid zone regions, highlighting the transitional nature of the region.

The average number of species trapped at each of the 24 sites was 9.8 (range 6–14). Burbidge et al. (2004) recorded an average of 10.4 vertebrate species (range 1–19) within 252 smaller 1 ha quadrats sampled in the Western Australian agricultural zone, to the south and west of the Mt Gibson and Karara–Lochada study sites. Burbidge et al. (2004) captured 16 small mammal species in the Western Australian agricultural zone. *M. musculus* was the most abundant small mammal. Three small mammal species captured at Mt Gibson and Karara–Lochada were not captured during the survey of the Western Australian agricultural zone: *N. yvonnae*, *N. mitchelli* and *N. alexis*, all of which occur on the extremities of their range further east. A previous trapping survey at Charles Darwin Reserve, immediately west of Mt Gibson, recorded five small mammal species, four of which were recorded in this study (Burbidge et al. 1989). Southgate and Masters (1996) recorded *P. hermannsburgensis, N. alexis* and *M. musculus* as the three dominant small mammals in the arid Wattarka National Park region in the Northern Territory, with three species of *Sminthopsis* captured regularly, but in lower numbers. These species represent a similar composition of native and introduced rodents and dasyurids to the suite of species recorded in this study.

Of the 30 reptile species trapped at Mt Gibson and Karara–Lochada, only two species were regarded as common (>120 captures): *C. mimetes* and *C. schomburgkii.* Other species captured regularly (>9 captures) included: *Ctenophorus reticulates*, *C.scutulatus*, *Diplodactylus pulcher*, *D. granariensis*, *Liopholis inornata*, *Gehyra variegata*, *Menetia greyii*, *Pogona minor* and *Varanus caudolineatus.* All these more common reptile species were captured at both stations, except *G. variegata*, which was only captured at Mt Gibson. Continued trapping at Mt Gibson on the same sites in 2008 revealed an additional three species of reptile (*Brachyurophis semifasciata*, *Rhamphotyphlops bicolour* and *Underwoodisaurus milii*; AWC unpub. data), and it is likely that additional searches and trapping, both within the grids and in adjacent areas within the same land system types, would unearth greater species richness. In particular, snakes, goannas and legless lizards are regarded as difficult to sample (Rolfe & McKenzie 2000).

Another 26 species of reptile have been captured or seen elsewhere on the 130,500 ha Mt Gibson Wildlife Sanctuary during previous and continued survey work, including: *Ctenophorus ornatus*, *C. salinarum*, *Ctenotus severus*, *Cyclodomorphus branchialis*, *Delma australis*, *D. butleri*, *Demansia psammophis*, *Lerista gerrardii*, *Lucasium maini*, *Eremiascincus richardsonii*, *Egernia depressa*, *Moloch horridus*, *Morethia butleri*, *M. obscura*, *Oedura reticulata*, *Parasuta monachus*, *Pseudonaja modesta*, *P. nuchalis*, *Pygopus nigriceps*, *Ramphotyphlops bicolour*, *R.* hamatus, *Simoselaps bertholdi*, *Strophurus strophurus*, *Tiliqua rugosa*, *Tiliqua occipitalis* and *Varanus tristis* (AWC unpub. data).

Fifty reptile species are therefore currently known to occur within the boundaries of the Mt Gibson Wildlife Sanctuary and Karara–Lochada pastoral leases. A broadscale stratified survey design at periods of peak reptile activity, which was not the intention of this study (instead based upon the relative abundance of vertebrate fauna during feral cat control activities; Richards & Algar 2008), would be required to more adequately sample faunal assemblages in the region.

Burbidge et al. (2004) captured 106 of the 142 reptile species known from the Western Australian agricultural zone. Those at Mt Gibson and Karara–Lochada represent a subset only. Burbidge et al. (1989) captured 29 reptile species at Charles Darwin Reserve, 18 of which were captured at Mt Gibson and Karara–Lochada also.

## Land System Faunal Associations

The faunal assemblages, while of generally similar composition with regard to dominant small mammal and reptile species, were significantly different, varying between stations, land systems and years. At Mt Gibson, the small vertebrate assemblages from the Joseph (YS) and Pindar (OP) land systems could not be separated, but were different to those in the Carnegie (SL) and Euchre (GR) land systems, and assemblages from the YS and GR land systems could not be separated, but were different to the other two land systems. At Karara–Lochada, all four land systems could be separated based on faunal assemblages except OP and YS, and GR and SL. Assemblages at Mt Gibson were different from those at Karara–Lochada in all but the YS land system.

Six species were primarily responsible for the differentiation in faunal assemblages between the two stations: *N. mitchelli*, *S. dolichura* and *C. mimetes* were more abundant at Mt Gibson and *C. schomburgkii; P. hermannsburgensis* and *M. musculus* were more abundant at Karara–Lochada. Many species were captured only as single records. More intensive, more widespread and longer-term trapping would no doubt reveal a more realistic description of the abundance and distribution across land system types. Landform and fire history were not taken into account during this study, and both may play an important role in determining species distribution and abundance. Each of the four land system types within each station was described by the relative abundance of the most common small mammal and reptile species, though there was considerable overlap in presence/absence of those species between land systems and stations.

## Changes in Relative Abundance between Years

The same six species were primarily responsible for the differentiation in faunal assemblage structure between years, with the four mammal species (*Notomys mitchelli*, *S. dolichura*, *P. hermannsburgensis* and *M. musculus*) and *Ctenotus mimetes* decreasing in abundance from 2006 to 2007, and *C. schomburgkii* increasing in abundance.

The below average rainfall recorded at Mt Gibson and Karara in 2007 may have contributed to the lower number of captures of small mammals and reptiles that year. The even lower captures of small mammals at Karara–Lochada in 2007 compared with 2006 may be due to the dry conditions, but in addition may also be due to a dramatic increase in fox numbers recorded throughout the station in the absence of predator control (Richards & Algar 2008; Algar & Richards 2010).

The population dynamics of arid zone mammals are typically driven by interactions between rainfall, resource availability and predation (Dickman et al. 2001). Some dasyurid species, such as *S. dolichura*, have predictable population fluctuations (Friend et al. 1997) while many rodents follow an eruptive pattern of rarity, and abundance when conditions are favourable (Predevac 1994). Rodents, particularly *N. alexis* and *P. bolami*, increased in abundance in the absence of predators (and rabbits) at the Arid Recovery Reserve in South Australia, however the abundance of most dasyurids and small lizards did not change significantly (Moseby et al. 2009). No such patterns were evident at the study sites during the two years of monitoring (Richards & Algar 2008; Algar & Richards 2010).

# CONCLUSIONS

The faunal assemblages of the Mt Gibson and Karara–Lochada pastoral leases are typical of those found in the region and are likely to characterize the transitional zone between the south-west and arid zone faunas associated with the Yalgoo, Avon Wheatbelt and Murchison IBRA Bioregions. Additional trapping effort across land system types, the removal of pseudo-replication and opportunistic sampling would no doubt provide a suite of additional species that occur at Mt Gibson and Karara–Lochada, and provide more generalized information about regional faunal composition. While the faunal assemblages are similar, the differences in assemblage composition and species abundance between and within the two stations highlights local site differences within the broad land system types categorized by Department of Agriculture and Food (Western Australia; DAFWA) and based on Beard's (1976) vegetation mapping of Western Australia.

The interactions between species and with environmental conditions are without doubt complex. As is usually the case, longer-term monitoring is required to tease out these relationships and would no doubt contribute to further knowledge of the fauna occurring within the Avon–Wheatbelt and Yalgoo Bioregions and the southern rangelands region of Western Australia.

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## REFERENCES

Algar D, Richards J (2010) Controlling introduced predators in the rangelands: the conclusion. *Landscope* **25,** 17–23.

Anderson MJ, Willis TJ (2003) Canonical analysis of principle coordinates: a useful method of constrained ordination for ecology. *Ecology* **84**, 511–525.

Anderson MJ, Gorley RN, Clarke KR (2008) *PERMANOVA + for PRIMER: Guide to Software and Statistical Methods.* PRIMER-E, Plymouth, UK.

Baynes A (2002) 'Final Report on the Original Mammal Fauna of Mount Gibson Station'. Unpublished Report.

Beard JS (1976) *The Vegetation of the Perenjori Area, Western Australia: Map and Explanatory Memoir 1:250,000 Series.* Vegmap Publications, Perth.

Burbidge AA, Dixon KW, Fuller PJ (1989) *The Flora and Fauna of Vacant Crown Land at White Well, Shire of Dalwallinu, Western Australia.* Technical Report No 24. Department of Conservation and Land Management, Perth.

Burbidge AH, Fuller PJ, McKenzie NL (1995) Vertebrate fauna. In *The Biological Survey of the Eastern Goldfields of Western Australia. Part 12. Barlee–Menzies Study Area* (eds GJ Keighery, NL McKenzie, NJ Hall). *Records of the Western Australian Museum* Supplement **49**, 208–245.

Burbidge AH, Johnstone RE, Fuller PJ, Stone P (2000) Terrestrial birds of the southern Carnarvon Basin, Western Australia: contemporary patterns of occurrence. *Records of the Western Australian Museum* Supplement **61**, 449–464.

Burbidge AH, Rolfe JK, McKenzie NL, Roberts JD (2004) Biogeographic patterns in small ground-dwelling vertebrates of the Western Australian wheatbelt. *Records of the Western Australian Museum* Supplement **67,** 109–137.

Clarke KR, Warwick RM (2001) *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation.* Natural Environmental Research Group, UK.

Cuthbert R, Hilton G (2004) Introduced house mice *Mus musculus*: a significant predator of threatened and endemic birds on Gough Island, South Atlantic Ocean? *Biological Conservation* **117**, 483–489.

Department of Agriculture and Food Western Australia (1990). *Soil – Land Systems of the South West of Western Australia.* Department of Agriculture and Food Western Australia, Perth.

Dickman CR, Haythornthwaite AS, McNaught GH, Mahon PS, Tamayo B, Letnic M. (2001) Population dynamics of three species of dasyurid marsupials in arid central Australia: a 10-year study. *Wildlife Research* **28**, 493–506.

Friend GR, Johnson BW, Mitchell DS, Smith GT (1997) Breeding, population dynamics and habitat relationships of *Sminthopsis dolichura* (Marsupialia: Dasyuridae) in semi-arid shrublands of Western Australia. *Wildlife Research* **24**, 245–262.

Kitchener DJ, Chapman A, Dell J, Muir BG, Palmer M (1980a) Lizard assemblage and reserve size and structure in the Western Australian wheatbelt – some implications for conservation. *Biological Conservation* **17**, 25–62.

Kitchener DJ, Chapman A, Muir BG, Palmer M (1980b) The conservation value for mammals of reserves in the Western Australian wheatbelt. *Biological Conservation* **18**, 179–207.

McKenzie NL (2000) Non-volant mammals of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement **61,** 479–510.

McKenzie NL, May JE (2003) *A Biodiversity Audit of Western Australia's Biogeographical Subregions in 2002.* Department of Conservation and Land Management, Perth.

McKenzie NL, Rolfe JK, Aplin KP, Cowan MA, Smith LA (2000) Herpetofauna of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement **61,** 335–360.

Moseby KE, Hill BM, Read JL (2009) Arid Recovery: a comparison of reptile and small mammal populations inside and outside a large rabbit, cat and fox-proof exclosure in arid South Australia. *Austral Ecology* **34**, 156–169.

Predevac M (1994) Population dynamics and environmental changes during natural irruptions of Australian desert rodents. *Wildlife Research* **21**, 569–582.

Richards J, Algar D (2008) Controlling feral animals in the rangelands. *Landscope* **23**, 52–58.

Rolfe JK, McKenzie NI (2000) Comparison of methods used to capture herpetofauna: an example from the Carnarvon Basin. *Records of the Western Australian Museum* Supplement **61,** 361–370.

Southgate R, Masters P (1996) Fluctuations of rodent populations in response to rainfall and fire in a central Australian hummock grassland dominated by *Plectrachne schinzii. Wildlife Research* **23**, 289–303.

Van Vreeswyk AME, Godden PT (1998) *Pastoral Resources and Their Management in the Sandstone – Yalgoo – Paynes Find Area, Western Australia.* Agriculture Western Australia, Perth.