# Relict *Bettongia lesueur* warrens in Western Australian deserts

**Andrew A. Burbidge[1], Jeff Short[2] and Phillip J. Fuller[1,3]**

[1]Department of Environment and Conservation, Western Australian Wildlife Research Centre, PO Box 51, Wanneroo, WA 6946, Australia.
Email: Andrew.Burbidge@dec.wa.gov.au

[2]CSIRO Sustainable Ecosystems, Private Bag 5, Wembley, WA 6913, Australia. Current address: Wildlife Research and Management Pty Ltd, PO Box 1360, Kalamunda, WA 6926, Australia.

[3]Current address: 3 Willow Rd, Warwick, WA 6024, Australia.



**ABSTRACT**

The Boodie or Burrowing Bettong *Bettongia lesueur* became extinct on the Australian mainland by about 1960 but, in some areas, left evidence of its previous distribution in the form of relict landscape features, which remain widespread in arid areas with hard soils. We recorded the location of landscape features ('mounds'), which we attributed to *B. lesueur*, in the western deserts during the 1980s and 1990s. There were two types of mounds — large, irregular shaped mounds of calcrete or clayey soils that were accumulated spoil from warren digging and smaller, regular, and largely circular mounds on lateritic surfaces. We mapped mounds, which are visible as obvious features in an otherwise often monotonous landscape, during vehicular traverses of desert tracks over a 10-15 year period. Mound density along one 215 km traverse in the northern Gibson Desert was 5.9±0.96 km$^{-2}$. We measured attributes of both types of mound in the Gibson Desert. The former persist as warrens (often occupied by Rabbits *Oryctolagus cuniculus*), have many entrances, are often large in aerial extent, and often associated with rock capping. The latter are largely symmetrical mounds, smaller (typically < 20 m in diameter), and with soil penetrability typically far greater than surrounding soil that often has a hard pan.

Key words: *Bettongia lesueur*, relict warrens, western deserts, Australia

## Introduction

The Boodie or Burrowing Bettong *Bettongia lesueur* once had a very wide distribution in the arid and semi-arid parts of Western Australia (WA), southern Northern Territory, most of South Australia, western New South Wales and parts of Queensland (Short and Turner 1993, Burbidge 1995, Van Dyck 2005), as well as five islands off the WA coast—Barrow, Boodie (immediately south of Barrow Island), Dirk Hartog, Bernier and Dorre (Shark Bay) (Abbott and Burbidge 1995). They became extinct on Dirk Hartog Island in the early 1900s (Burbidge and George 1978, Baynes 1990) and on Boodie Island in 1985. The extinction on Dirk Hartog Island has been attributed to predation by feral cats *Felis catus* (Short *et al.* 1992; this conclusion was supported by the analyses of Burbidge and Manly 2002), while the extinction on Boodie Island probably resulted from a successful 1985 campaign to eradicate black rats *Rattus rattus* (Short and Turner 1993, Morris 2002). The species was successfully reintroduced to Boodie Island in 1993 (Morris 2002).

*B. lesueur* was one of many species of mostly medium-sized Australian mammals to become extinct on the Australian mainland (Burbidge *et al.* 1988). Extinction has been attributed to predation by the European red fox *Vulpes vulpes* and feral cat, although changed land use practices and fire regimes may have contributed in parts of the continent (Johnson *et al.*1989, Short and Smith 1994). The last museum specimen was from the south west of WA in the 1940s (Short and Turner 1993) and the last oral history records were from the Gibson Desert where it was reported to be present about 25 years before the mid-1980s, ie about 1960 (Burbidge *et al.* 1988). Unlike other extinct species, however, they left evidence of their occupation in the form of relict warrens, still visible in many areas with hard soils.

The persistence of *B. lesueur* warrens in arid Australia has been understood for some time. Burbidge *et al.* (1988) documented the widespread distribution of *B. lesueur* and relict warrens in the Great Sandy, Little Sandy, Gibson and Tanami Deserts but provided only general location details. Frith (1973) noted their presence across the plains of New South Wales, and Noble (1993) and Noble *et al.* (1997, 2000) described the current appearance of warrens in western New South Wales and near Uluru in some detail. This paper documents the distribution of landscape features we believe are relict warrens (here collectively termed 'mounds') in the western deserts of Western Australia. We provide information on abundance of these mounds, describe the two major types, and provide information on their structure.

## Methods

### Distribution and abundance of relict warrens

Over many years two of us (AAB and PJF) recorded the locations of mounds, believed to be relict *B. lesueur* warrens, while driving in outback WA. Both Type 1 and Type 2 (see below) mounds were recorded when visible from a vehicle travelling at slow speed over rough outback tracks. Most of the records were obtained while conducting oral history research into the distribution and conservation status of desert mammals in the early- to mid-1980s (Burbidge *et al*. 1988) and during research into fire ecology in the Gibson Desert in the late 1980s and early 1990s; however, additional data were collected opportunistically during other work (eg, searches for *Lagorchestes hirsutus* in the Great Sandy and Little Sandy Deserts (Burbidge and Pearson 1989). On occasions, we questioned local Aborigines about their knowledge of these relict features.

In May 1986, AAB and PJF counted mounds while driving from Sandy Blight Junction (23°12'S, 129°33'E) in the Northern Territory to Gary Junction 22°30'S, 125°15'E) and then to Windy Corner (23°34'S, 125°11'E) in Western Australia. The number of mounds 75 m either side of the track was counted in 5 km blocks, ie, each 'quadrat' was 75 ha. Whether mounds were less than 75 m from the vehicle was a judgement made after initial calibration of the observers by testing the correctness of their observations using measurements. Vehicle speed varied with track conditions, but was usually between 5 km $h^{-1}$ and 30 km $h^{-1}$.

### Measurements of relict warrens

Measurements of relict warrens were made by JS in the Gibson Desert between Mount Beadell (25°32'S, 125°16'E) and Lake Gruszka (25°19'S, 125°34'E) in September 1989. Eleven sites were assessed and these were of two distinct types. The first type (Type 1 mounds) were currently occupied by Rabbits *Oryctolagus cuniculus* with many entrances dug under rock capping and with large mounds of spoil. Three Type 1 mounds were measured. The second and more abundant type (Type 2) were circular mounds dotted across lateritic plains. The number of active and inactive entrances was recorded and the dimensions of the site were recorded. The presence or absence of rock capping was noted and the height of rock covering entrances was measured. The slope of the site was measured with an inclinometer. Notes were made on plant cover.

The penetration resistance of soils around Type 2 mounds was assessed using an impact penetrometer. An illustration of the penetrometer and the methodology of use are given in Parer and Libke (1985). The number of drops of a 9-kg weight to drive a cone-tipped shaft through five successive 15 cm layers of soil starting at the soil surface was recorded. Measurements were taken at two random points in the centre of the mound and at two points 10 m beyond the margin of the mound. If more than 40 drops were required to drive the cone tip through a 15 cm layer then this layer was considered impenetrable and given a value of 40. In such a case, no attempt was made to obtain a measurement from deeper layers. A value of one drop per 15 cm with the impact penetrometer corresponded to a force of about 110 Newtons $cm^{-2}$ (Parer and Libke 1985). Data were transformed using natural logs to ensure homogeneity of variance and tested using a general linear model.

## Results

### Distribution and abundance of relict warrens

Mounds that we recorded as being relict *B. lesueur* warrens were of two main types. Type 1 consisted of large (up to 90 m or more in width) undulating areas within calcrete or clayey soils, sometimes below rock capping. In one Type 1 mound in calcrete near Kiwirrkurra (22°49'S, 127°45'E) skeletal remains of Western Quoll *Dasyurus geoffroii* were located (Burbidge *et al.* 1988). In 1987 we excavated > 1 m deep trenches across three Type 1 mounds near 29°S,128°30'E, which were not occupied by *O. cuniculus*, to search for further skeletal remains, but did not locate any. We found that discernable, mostly collapsed tunnels could be located up to one metre below the surface.

Type 2 features were fairly regular and roundish mounds, occurring mostly on lateritic surfaces, mainly in the Gibson Desert. These were usually about 10-20 m across and 0.5-1 m above the surrounding country. Often they could be recognised from a considerable distance, not only because of their slight elevation, but also by the different vegetation growing on them—soft grasses and ephemeral forbs including everlastings (*Rhodanthe* spp.) and mulla mullas (*Ptilotus* spp.). They could also be recognised from an aircraft. We excavated five of these mounds in the Gibson Desert and found that the disturbed soil extended beyond a metre in depth.

Figure 1 shows the location of relict features identified as *B. lesueur* warrens.

On the traverse from Sandy Blight Junction to Gary Junction mounds were visible in almost all areas with hard soils (loams, lateritic surfaces, calcrete, and even lateritic 'buckshot' plains). Areas of sand dunes and sand plains showed no evidence of old warrens. From the WA-NT border 215 km westwards, we recorded 191 relict mounds in areas of hard soils within the 150 m wide strip (mean 4.44 warrens per 75 ha quadrat, range 0-21, SE = 0.72), see Figure 2. This is a mean of 5.9 ± 0.96 $km^{-2}$.

### Warren measurements

Type 1 mounds had a mean number of 43 entrances (31 active) and average dimensions of 55 x 28 m. The largest covered an area of 88 m by 30 m and had 53 entrances, 43 of which were active. These three warrens were typically in gravelly loam/clay soil in areas of mulga and without *Triodia*. All were associated with rock capping. Type 1 features at this location were in the soil landscape (BB18) described as small valley plains with calcrete (kunkar) platforms and soils chiefly calcareous loams (Bureau of Rural Sciences 1991). *O. cuniculus* were abundant and still using them as were various varanids. Mounds of spoil excavated from burrows were piled to 80 cm above ground

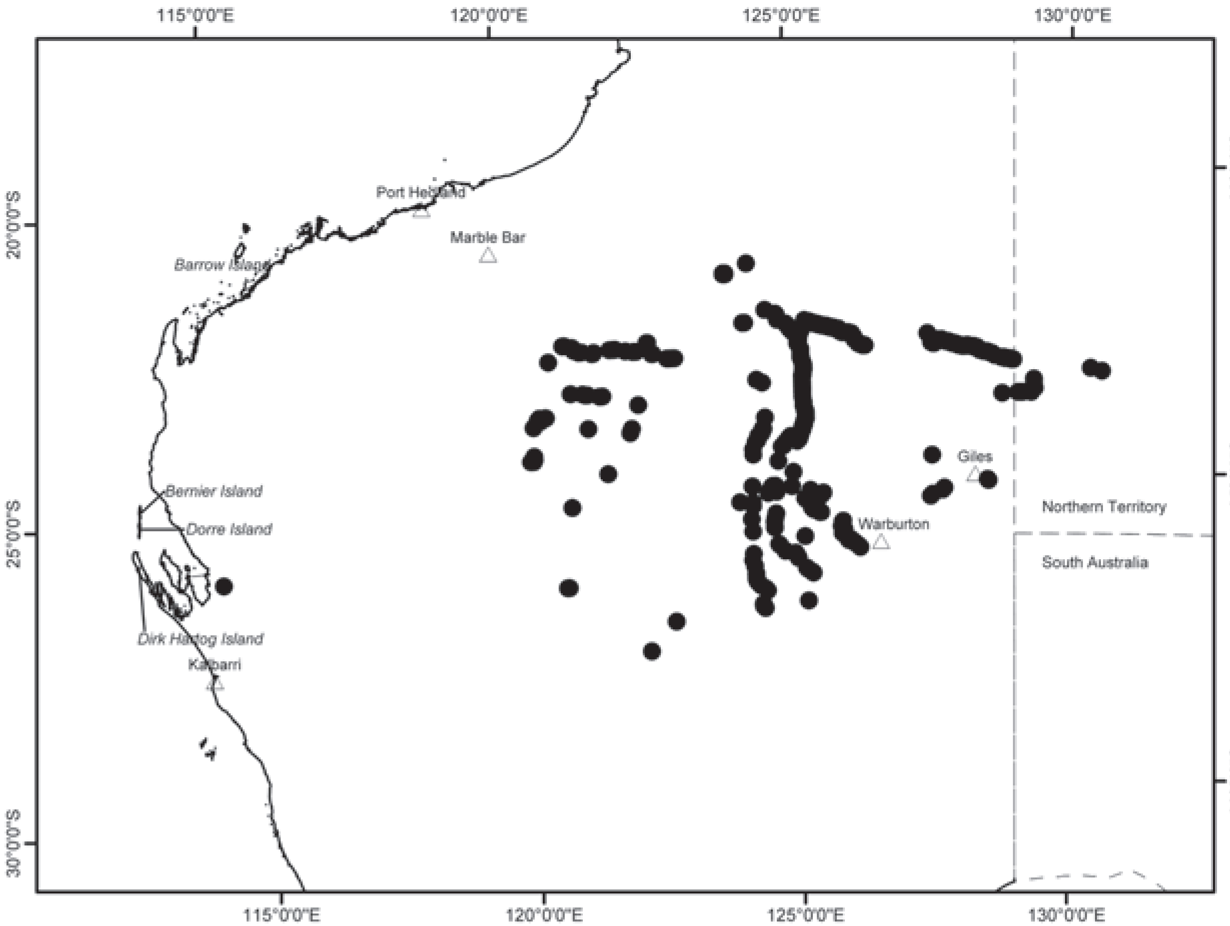


Figure 1. Map of central Western Australia showing locations of mounds recorded in the 1980s and 1990s believed to be relict boodie warrens.

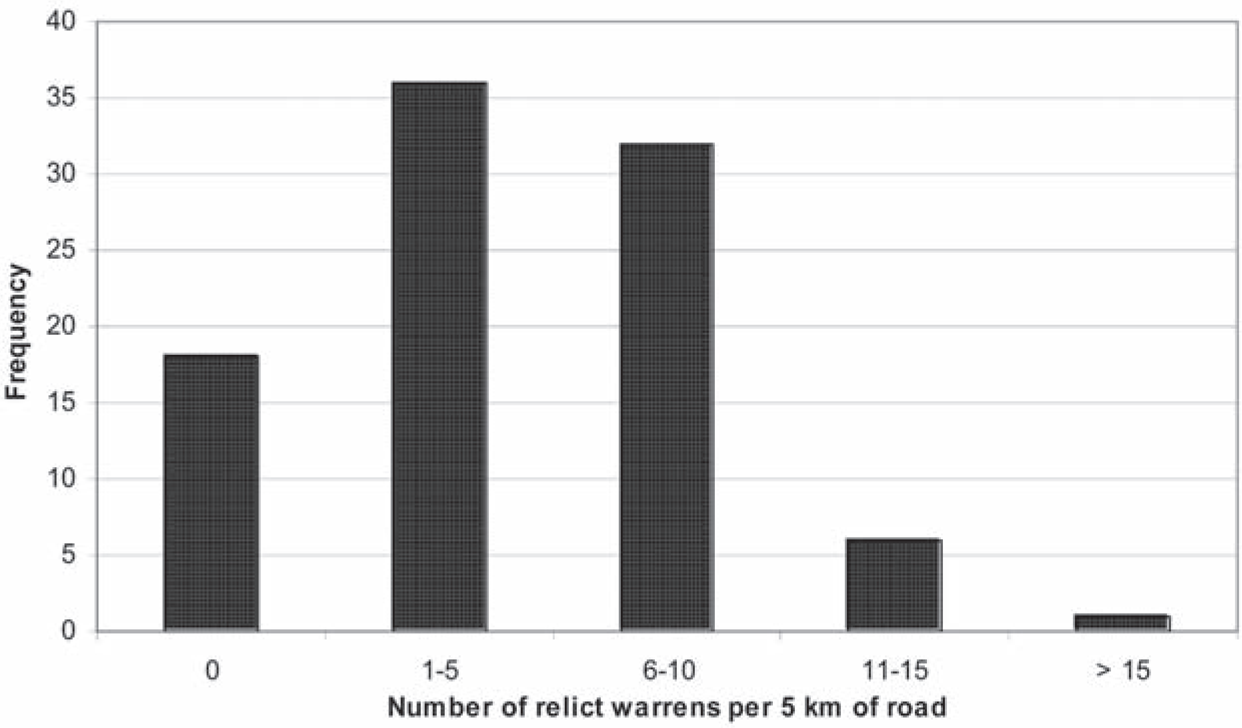


Figure 2. Frequency histogram of number of relict warrens recorded in 5 km of traverse.

level and were extensive. The average height of rock capping above burrow entrances were 33.4 ± 4.2 cm (mean ± SE; n = 15) and at some sites were further covered with spoil of 30 – 60 cm in height.

Type 2 mounds were roughly circular and averaged 17 m across (length 16 – 21 m; width 13 – 18 m), about 50 cm above ground level at their highest point (range 38-90) and were located on lateritic plains with a slope of < 2° (range 0.5 – 1.25°). This soil landscape (BE12) is described as broad gently undulating plateau ridges and pediments with extensive gravel pavements, some small sandy plains, and small tracts of longitudinal dunes with the chief soils being shallow earthy loams and shallow red earths underlain by a red-brown hardpan (Bureau of Rural Sciences 1991).

All had a cover of *Triodia basedowii* of from 25-40% cover and a sparse cover of yellow or pink everlastings. There were no shrubs on measured mounds, but a range of sparse shrubs nearby varying from mound to mound (*Hakea suberea*, *Eremophila* spp, *Acacia* sp., *A. aneura*). No *O. cuniculus* activity or burrows were recorded at any of the eight mounds examined. Two of eight mounds had a single entrance burrow (ca 1.5 m long and 600 mm deep) attributed to *Varanus* sp. Logged penetrometer readings showed a significant interaction between location (the centre of the mounds versus 10 m off the mounds) and depth ($F_{4, 128} = 3.16$, p = 0.016). Overall the soil on the mounds was far more penetrable to the depth of measurement (Figure 3). The difference in number of drops of the 9 kg weight between the centre of the mound and 10 m beyond to drive the penetrometer through successive layers to 75 cm varied between 2- and 5-fold across the eight measured mounds, being greatest at the 30-45 cm layer.

Three of the eight sites had hard pans beyond the mound that were impenetrable to the penetrometer (both attempts at the site failed to penetrate). This hard pan was at 30-60 cm at one site and at 45-60 cm at two other sites. Three other sites had one reading off the warren that suggested a more variable hard pan (one impenetrable at 0-15 cm, one at 15-30 cm, and one at 45-60 cm). In combination, this result suggests soil characteristics challenging for a burrowing animal, but with opportunities to find breaks in the hard pan layer.

## Discussion

*Bettongia lesueur* is unique among Australian medium-sized mammals in permanently inhabiting warrens. Social organisation and warren use of a semi-captive population at Shark Bay have been described by Sander *et al.* (1997) and warren use and home range have been described for Barrow Island by Short and Turner (1990), at Heirisson Prong by Robley (2000) and within enclosures at the Arid Recovery site in South Australia by Finlayson and Moseby (2004). The latter populations were sourced from islands in Shark Bay.

Short (1999) suggested that *B. lesueur* burrows and warrens appeared to fall into two broad types depending on the substrate: complex multi-entrance warrens in rocky

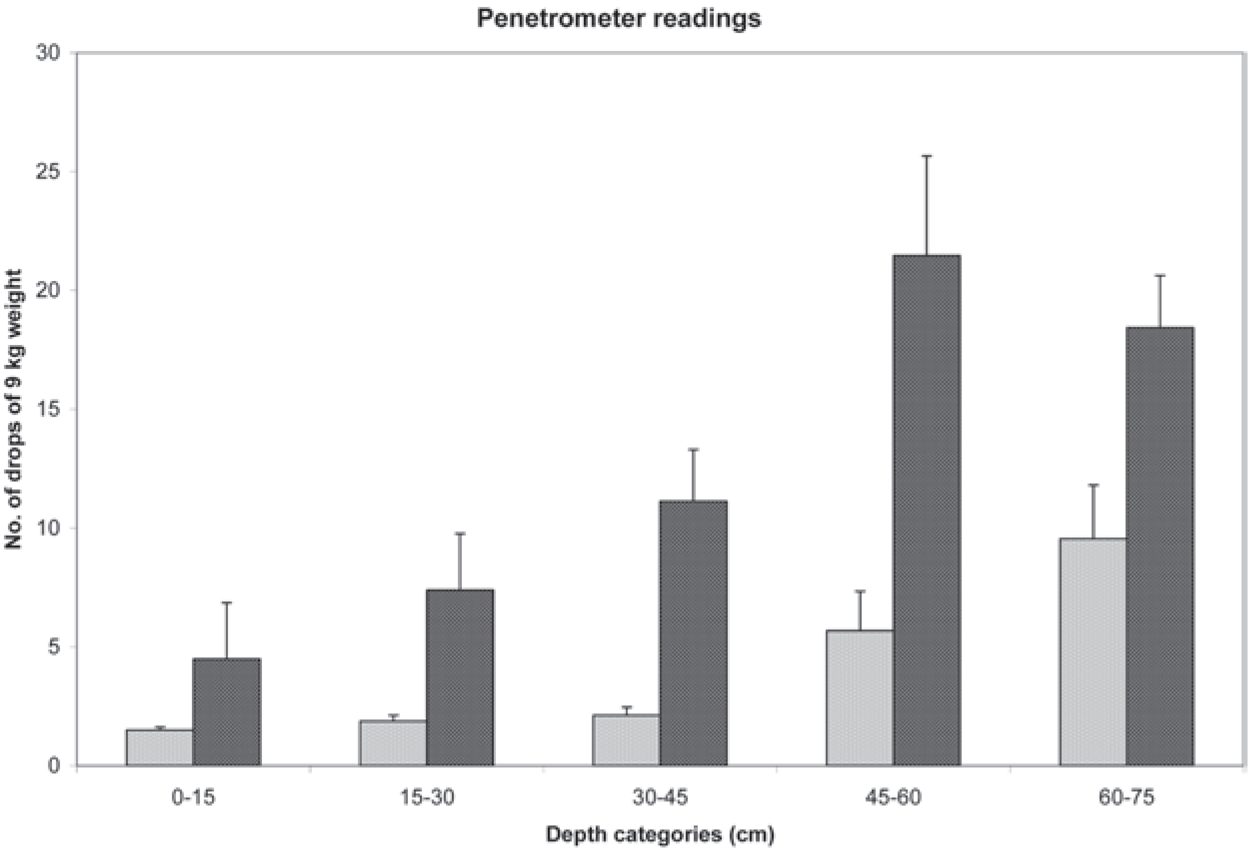


**Figure 3.** Penetrometer readings at the centre and at 10 m from the edge of warrens in the Gibson Desert. Left hand histogram is centre point of warren; right hand is 10 m from edge. Histograms show means, error bars are standard errors.

substrate or in a soil type that readily supported burrows; or simple burrows with few entrances. Examples of the former include those described by Gilbert in south-west WA in the 1840s (Gould 1863), Tipping (1979) in the south-west of NSW in the 1860s, Terry (1930 in Parker 1973) in the Tanami Desert of the Northern Territory, Giles (1889) in the bed of Lake Christopher at the western end of the Rawlinson Range, WA, and Short *et al.* (1989) for Barrow Island, WA. Examples of the latter include those in sandy or loamy substrates (Ride *et al*. 1962, Finlayson 1958) in coastal WA or central Australia. For example, warrens at Heirisson Prong in sandy substrate rarely exceed three entrances (mean of 2.4 entrances (n = 51): Robley (2000).

Type 1 relict warrens we have described from the Gibson Desert clearly match the complex multi-entrance warren described by Short (1999) and earlier authors. They match Noble's (1993) 'larger' features. Type 2 relict warrens less clearly fit historical or current descriptions of *B. lesueur* warrens. The possibility that other animals may have constructed the mounds in the Gibson Desert should be considered. The only other species that occurred in the western deserts in recent times that might have done so is the Malleefowl *Leipoa ocellata*. At 'Lake Mere' station in western New South Wales Noble (1993) described low circular features (around 10 m in diameter) characterised by a relatively high density of surface pebbles, particularly around the outer perimeter zone, some of which had a clearly defined central depression 15-20 cm deep, while others were nearly flat. He attributed these soil-surface features to *L. ocellata*.

However, it is our view that the circular mounds we ascribe to *B. lesueur* were not constructed by *L. ocellata* because:

- we were told by Aboriginal informants that *B. lesueur* were widespread in the Gibson Desert and that both Type 1 and Type 2 mounds were once occupied by *B. lesueur* and Common Brushtail Possums *Trichosurus vulpecula*; sometimes they mentioned other animals that also occupied them, such as *D. geoffroii* (Burbidge *et al*. 1988),
- many mounds occur well to the north of the known *L. ocellata* distribution in Western Australia as given by Benshemesh (2000),
- at 10-20 m in diameter, they are much broader than *L. ocellata* mounds, which, when in use are about 3-5 m in diameter and about 1 m high (Priddel and Wheeler 1994, 2003, Benshemesh 2000); the largest mound recorded by Frith (1962) was 18 feet (5.7 m) in diameter and four feet (1.3 m) high,
- *L. ocellata* require sandy or loamy substrates with leaf litter to construct nest mounds (Frith 1962); relict mounds that we consider to have been constructed by *L. ocellata* in the southern Gibson Desert are in areas with loamy soils dominated by mulga *Acacia aneura*; however, most mounds we ascribe to *B. lesueur* are in lateritic *Triodia*-dominated landscapes with no leaf litter. Noble (1999) reports a personal communication from J. Benshemesh that abundant leaf litter is not a prerequisite for incubation mound building by *L. ocellata* in arid north-western South Australia. As the mounds survive for a long time, the vegetation may have been different when they were constructed, but it is unlikely that the soil type would have changed, and
- features we believe are old *L. ocellata* mounds in the Gibson Desert Nature Reserve near Young Range (24º56'S, 125º03'E) consist of an only slightly raised area with abundant large stones on the surface, mainly around the perimeter, similar to Noble's (1993) Class IV smaller features; the mounds we ascribe to *B. lesueur* consist of evenly-mixed stones and soil.

Noble (1999) described 'large circular mounds with diameters commonly around 20 m' in semi-arid New South Wales and Queensland, as well as larger *c*. 100 m diameter sub-circular features. He hypothesised that the former were constructed by extinct megapodes that weighed about 7 kg (compared with 1.5-2.5 kg for the extant *L. ocellata*), and the latter by an extinct analogue of *B. lesueur*. Based on our observations in the Gibson Desert, we suggest that *B. lesueur* could have been the builder of both of Noble's (1999) circular mounds (our Type 2) and sub-circular mounds (our Type 1).

Disused *B. lesueur* warrens are still widespread in suitable soils in the deserts of WA. Some show evidence of current or past use by *O. cuniculus*, particularly in calcrete and gypseous mounds in salt lake systems, but many, especially in northern deserts, show little or no evidence of recent digging and have collapsed (Burbidge *et al*. 1988). In some areas, the mounds remain as obvious features in an otherwise often monotonous landscape; this is the case in the Gibson Desert. While sandy soils, such as the extensive dune and inter-dune sandplains, where low-lying areas were favoured as warren sites, now show no evidence of occupation by *B. lesueur*, many such areas would once have had warrens, eg, Wood Jones (1924) for South Australia, Dahl (1926) for the Broome area and Burbidge *et al.* (1988) for the western deserts.

The density of Type 1 and 2 mounds recorded on the traverse in the southern Great Sandy and northern Gibson Deserts (*ca* 5 $km^{-2}$) is higher than the density reported for *B. lesueur* warrens on Barrow Island. Short *et al*. (1989) suggest a total of about 120 warrens on Barrow Island (*ca* 0.5 $km^{-2}$). Bamford and Bamford *et al.* (2005) located nine *B. lesueur* warrens in a 658 ha area of Barrow Island (1.4 $km^{-2}$), with six being actively used. Thus it seems unlikely that all warrens we observed would have been inhabited simultaneously. The mounds apparently survive as topographical features for a long time and occupation is likely to have varied over time and also with climatic conditions.

Short *et al*. (1989) attempted to trap all *B. lesueur* in two warrens on Barrow Island with 19 and 25 entrances and captured 17 and 18 individuals respectively; these authors suggested a total population of about 20 in each. Some warrens on Barrow Island have many more entrances: Short *et al*. (1989) report warrens of up to 91 entrances. In February 1981, two of us, with several other observers, counted 32 boodies leaving a warren with 67 entrances.

The Gibson Desert and more northern deserts in Western Australia have high maximum recorded soil temperatures, with February values exceeding 36°C at 1 m, and, to the north of Windy Corner, exceeding 39°C at this depth (Parer and Libke 1985). Parer and Libke estimated mean soil temperatures at 50 cm depth of 35-36°C in February in extreme years for their site in central NSW. Such high temperatures in the burrow would result in high evaporative and respiratory water loss resulting in acute water shortage for *O. cuniculus*. Hence, this is a particularly challenging thermal environment for burrowing animals and requires deep burrows or burrows protected by rock or a calcareous layer for animals to persist. Alternatively access to free water or succulent vegetation may provide sufficient water for metabolism. Access to succulent chenopods enables *O. cuniculus* to penetrate and survive the Nullarbor and arid playas.

The presence of hard pans below the surface (such as recorded at our Type 2 mounds in the Gibson Desert) may limit the ability of animals to construct deep burrows. *O. cuniculus* is one species unlikely to be able to dig through a pan that requires > 30 drops of the penetrometer to penetrate a 15 cm layer (Parer and Libke 1985). However, *O. cuniculus* are considered weak diggers with no special adaptation for digging, compared with marsupials such as *B. lesueur*, Bilbies *Macrotis lagotis* and wombats *Vombatus ursinus* and *Lasiorhinus* spp. Various authors have suggested that *O. cuniculus* has only been able to establish and persist in areas of hard or rocky soils because of the prior presence of burrows created by marsupials (Aitken 1971). Many of the "refuge warrens" for *O. cuniculus* were "old, large and deep and were located on soil types with a hard layer at a shallow depth" (Myers and Parker 1975), and likely not dug by *O. cuniculus* (Parer and Libke 1985).

The high mounds of spoil on the calcrete warrens (to 0.8 m) would contribute to the insulative properties of the warrens reducing summer temperatures in the burrows below (effectively increasing the depth of tunnels) and creating a more favourable microclimate. Similarly, the large number of entrances facing in a variety of directions would increase the prospect of ventilation of the warren and provide areas within the warren to offload metabolic heat production (Parer and Libke 1985).

The extreme hardness of the soil adjacent to Type 2 mounds at many locations in the Gibson Desert with a widespread hardpan and the clear difference in penetrability between mound areas and areas off the mound suggest that any warrens constructed in this soil type would have been made by an animal with a considerable digging ability. This provides additional independent corroboration that they were made by *B. lesueur* rather than by *L. ocellata*.

Relict warrens occur also in other parts of Western Australia. The warren marked on Figure 1 near Shark Bay (McKenzie *et al*. 2000) was a Type 1 mound similar to those in calcrete in the western deserts. Most mounds outside the western deserts have been taken over by *O. cuniculus*, which in some areas may have co-occurred with *B. lesueur* in the same warren, as documented by Wood Jones (1924) in South Australia, Burbidge *et al*. (1988) in central Australia, and Robley (2000) in Western Australia.

## Acknowledgements

We thank Tony Start who provided helpful comments on a draft of this paper and Nathan Eaton of DEC's Land Information Branch for preparing Figure 1. Our thanks also go to Jim Noble and Bill Low for helpful comments when refereeing a draft of this paper.

## References

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

**Aitken, P.F. 1971.** The distribution of the hairy-nosed wombat *Lasiorhinus latifrons* (Owen) Part 1: Yorke Peninsula, Eyre Peninsula, the Gawler Ranges and Lake Harris. *South Australian Naturalist* **45**: 93-103.

**Bamford, M.J. and Bamford, A.R., Biota Environmental Services and RPS Bowman Bishaw Gorham 2005.** Mammals and Reptiles. Technical Appendix C2, Draft Environmental Impact Statement/ Environmental Review and Management Programme for the proposed Gorgon Development. Chevron Australia, Perth

**Baynes, A. 1990.** The mammals of Shark Bay. Pp. 313-25 in *Research in Shark Bay. Report of the France-Australe Bicentenary Expedition Committee*, edited by P.F. Berry, S.D. Bradshaw, and B.R. Wilson. Western Australian Museum, Perth

**Benshemesh, J. 2000.** National recovery plan for malleefowl. Environment Australia, Canberra.

**Burbidge, A.A. 1995.** Burrowing bettong *Bettongia lesueur*. Pp. 289-291 in *The Mammals of Australia*, edited by R. Strahan. Reed Books, Chatswood, NSW.

**Burbidge, A.A. and George, A.S. 1978.** The flora and fauna of Dirk Hartog Island, Western Australia. *Journal of the Royal Society of Western Australia* **60**: 71-90.

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

**Burbidge, A.A. and Manly, B.F.J. 2002.** Mammal extinctions on Australian islands: causes and conservation implications. *Journal of Biogeography* **29**: 465-474.

**Burbidge, A.A. and Pearson, D.J. 1989.** A search for the Rufous Hare-wallaby in the Great Sandy and Little Sandy Deserts, Western Australia, with notes on other rare mammals. Technical Report No. 23, Department of Conservation and Land Management, Perth.

**Bureau of Rural Sciences (1991).** Digital Atlas of Australian Soils (ARC/INFO® vector format) [on-line] Accessed 2006. http://www.brs.gov.au/data/datasets.

**Dahl, K. 1926.** *In Savage Australia. An Account of a Hunting and Collecting Expedition to Arnhem Land and Dampier Land*. Philip Allen, London.

**Finlayson, H.H. 1958.** On Central Australian mammals. Part III. The potoroinae. *Records of the South Australian Museum* **13**: 235-307.

**Finlayson, G.R. and Moseby, K.E. 2004.** Managing confined populations: the influence of density on the home range and habitat use of reintroduced burrowing bettongs (*Bettongia lesueur*). *Wildlife Research* **31**: 457-463.

**Frith, H.J. 1962.** *The Mallee Fowl.* Angus and Robertson, Sydney.

**Frith, H.J. (1973).** *Wildlife Conservation*. Angus and Robertson, Sydney.

**Giles, E. 1889.** *Australia Twice Traversed: The Romance of Exploration, Being a Narrative Compiled from the Journals of Five Exploring Expeditions into and through Central South Australia and Western Australia, from 1872 to 1876*. Sampson Low, Marston, Searle and Rivington, London.

**Gould, J. 1863. The Mammals of Australia.** Author, London.

**Johnson, K.A., Burbidge, A.A. and McKenzie, N.L. 1989.** Australian Macropodoidea: causes of decline and future research and management. Pp. 641-657 in *Kangaroos, wallabies and rat-kangaroos* edited by G.C. Grigg, P.J. Jarman and I.D. Hume. Australian Mammal Society, Sydney

**McKenzie, N.L., Hall, N. and Muir, W.P. 2000.** Non-volant mammals of the southern Carnarvon Basin, Western Australia. *Records of the Western Australian Museum* Supplement No. 61: 465-477.

**Morris, K.D. 2002.** The eradication of the black rat (*Rattus rattus*) on Barrow and adjacent islands off the north-west coast of Western Australia. Pp. 219-225 in *Turning the tide: the eradication of invasive species*, edited by C.R. Veitch and M. N. Clout. IUCN SSC Invasive Species Specialist Group, Auckland

**Myers, K. and Parker, B.S. 1975.** Effect of severe drought on rabbit numbers and distribution in a refuge area in semiarid north-west New South Wales. *Australian Wildlife Research* **2**: 103-120.

**Noble, J.C. 1993.** Relict surface-soil features in semi-arid mulga *Acacia aneura* woodlands. *Rangeland Journal* **15**: 48-70.

**Noble, J.C. 1999.** Fossil features of mulga *Acacia aneura* landscapes: possible imprinting by extinct Pleistocene fauna. *Australian Zoologist* **31**: 396-402.

**Noble, J.C. Low, W., Jacobson, G, Gillen, J. and Mutitjulu Community 1997.** Mitika mounds at Uluru-Kata Tjuta: mesoscale patterns and processes. Pp. 79-90 in *Back to the future. Proceedings, Natural Resources Workshop, Uluru-Kata Tjuta National Park, August, 1997*. AGSO Record 1997/55.

**Noble, J.C., Gillen, J., Jacobson, G., Low, W.A., Miller, C. and Mutitjulu Community 2000.** On taphonomy and the reintroduction of mitika (*Bettongia lesueur*) into Uluru-Kata Tjuta: an eco-geological perspective. Pp. 35-42 in *Biodiversity and the Re-introduction of Native Fauna at Uluru-Kata Tjuta National Park* edited by J.S Gillen, R. Hamilton, W.A. Low and C. Creagh. Bureau of Rural Sciences, Kingston

**Parer, I. and Libke, J.A. 1985.** Distribution of rabbit, *Oryctolagus cuniculus*, warrens in relation to soil type. *Australian Wildlife Research* **12**: 387-405.

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

**Priddel, D. and Wheeler, R. 1994.** Mortality of captive-raised malleefowl (*Leipoa ocellata*) released into a mallee remnant within the wheat-belt of New South Wales. *Wildlife Research* **21**: 543-551.

**Priddel, D. and Wheeler, R. 2003.** Nesting activity and demography of an isolated population of malleefowl (*Leipoa ocellata*). *Wildlife Research* **30**: 451-464.

**Ride, W.D.L., Mees, G.F., Douglas, A.M., and Tyndale-Biscoe, C.H. 1962.** The results of an expedition to Bernier and Dorre Island Shark Bay, Western Australia. Fauna Bulletin No. 1. Fisheries Department, Perth.

**Sander, U., Short, J. and Turner, B. 1997.** Social organisation and warren use of the burrowing bettong, *Bettongia lesueur* (Macropoidea: Potoroidae). *Wildlife Research* **24**: 143-157.

**Robley, A. J. 2000.** The comparative ecology of the burrowing bettong (*Bettongia lesueur*) and the European rabbit (*Oryctolagus cuniculus*). PhD thesis, Murdoch University, Perth.

**Short, J. 1999.** Decline and recovery of Australian mammals, with particular emphasis on the burrowing bettong, *Bettongia lesueur*. PhD. Thesis. Murdoch University, Perth, Western Australia.

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

**Short, J. and Smith, A.P. 1994.** Mammal decline and recovery in Australia. *Journal of Mammalogy* **75**: 288-297.

**Short, J., Turner, B. and Majors, C. 1989.** The distribution, relative abundance and habitat preferences of rare macropods and bandicoots on Barrow, Boodie, Bernier and Dorre Islands. Australian National Parks and Wildlife Service, Canberra.

**Short, J. and Turner, B. 1990.** The experimental reintroduction of the burrowing bettong to mainland Australia. Part II The importance of a vegetation mosaic to the burrowing bettong. 1990. World Wide Fund for Nature Australia, Sydney.

**Short, J. and Turner, B. 1993.** The distribution and abundance of the burrowing bettong (Marsupialia: Macropodoidea). *Wildlife Research* **20**, 525-534.

**Tipping M. 1979.** *Ludwig Becker Artist and Naturalist with the Burke and Wills Expedition*. Melbourne University Press, Melbourne.

**Van Dyck, S. 2005.** Queensland's burrowing bettongs… when old news is gut news. *Australian Zoologist* **33**: 60-68.

**Wood Jones F. 1924. The mammals of South Australia. Part II. The bandicoots and herbivorous marsupials**. Government Printer, Adelaide.