CALMScience 3(2): 125–147 (2000)

A review of the biology and conservation status of the Ngadji, *Pseudomys chapmani* Kitchener, 1980 (Rodentia: Muridae)

A.N. START[1*], S. D. ANSTEE[2] AND M.ENDERSBY[3]

[1] Department of Conservation and Land Management, PO Box 942, Kununurra, Western Australia 6743

[2] Hamersley Iron Pty Ltd, GPO Box A42, Perth, Western Australia 6001

[3] BHP Iron Ore Pty Ltd, PO Box 655, Newman, Western Australia 6753

*Address for correspondence

SUMMARY

The Ngadji, *Pseudomys chapmani*, was described in 1980 and recognized as the builder of pebble-mounds in the Pilbara and adjacent regions of Western Australia. At that time its range was thought to have declined substantially and it was declared by the State Minister to be 'fauna that is likely to become extinct or is rare'. Since then, it has been found on many sites associated with development projects, particularly iron ore mining, in the Pilbara. This prompted mining companies to undertake research on Ngadji status and biology. That culminated in a review and subsequent deletion from threatened fauna lists. Much of the new information is located in reports that are not generally available. This paper redresses that situation. While we have not attempted a re-evaluation of the review here, our data support its conclusions and we endorse the recommendations made in it.

Ngadji pebble-mounds can be distinguished from pebble mounds of other sympatric species and only Ngadji construct and maintain them. Ngadji have disappeared from about 35 per cent of their former extent of occurrence (340 000 km^2), mostly in Pilbara coastal ranges and the Gascoyne and Murchison regions. The pattern of decline suggests that foxes may have been instrumental, but cats and stock may have played a part. Fire was probably not important. Mounds probably allow these small rodents to obtain adequate nest insulation in stony, arid uplands, while aspects of mound occupation and the animals' biology enable them to accommodate energetic constraints and a 'boom-bust' life-mode. This life-mode requires pragmatic interpretation of IUCN criteria for establishing their conservation status.

INTRODUCTION

Pseudomys chapmani Kitchener, 1980 was described from four specimens collected at West Angelas, south-east Pilbara region, Western Australia (WA). Seven paratypes already in the Western Australian Museum collection had been obtained during the 1950s at Woodstock, Mt Edgar, and White Springs in the east Pilbara and misidentified as *P. hermannsburgensis*. The Woodstock specimens were dug from a 'mound, with small stones on a stony ridge', those from White Springs were collected 'in stony mounds' and the mice were commonly trapped 'nearby such mounds' at West Angelas (Kitchener 1980).

In WA, naturalists had associated pebble-mounds with mice for many years. Thus Davies (1970) listed '*Leggadina* Stone-Nest Mouse' in the fauna of Mileura Station because 'the old nests – survive on Mt Hale' but he considered it 'probably already extinct'. Ride (1970 p. 154) used 'Pebble Mound Mouse' and 'Sandy Inland Mouse' as alternative common names for *P. hermannsburgensis* noting (p. 152) it 'is widespread and common in the Pilbara and the Centre where it lives in shallow burrows often on stony ridges beneath piles of small pebbles'. Watts and Aslin (1981 p. 191) noted that, in the Pilbara, *P. hermannsburgensis* 'can be found in burrows within termite mounds, as well as in burrows marked by pebble-mounds' but referred to Kitchener (1980) in a footnote (p. 189).

From field experience and observations of a captive mouse housed with pebbles from its mound, Dunlop and Pound (1981) suggested that '*P. chapmani* builds pebble mounds and *P. hermannsburgensis* merely uses these nests in the Pilbara on an opportunistic basis. Thus the common name Pebble-mound Mouse should properly be assigned to *P. chapmani* whereas *P. hermannsburgensis* should be referred to only as the Sandy Inland Mouse.' Other species of mice are now known to build pebble-mounds in Australia (see below) and so *P. chapmani* is called the Western Pebble-mound Mouse (Start and Kitchener 1995) or Ngadji, the Panyjima[1] name for the species. We follow Braithwaite *et al.* (1995) and use Ngadji as the common name and treat it as singular or plural, like Chuditch and sheep.

[1] The Panyjima people are the traditional Aboriginal owners of part of the Hamersley Range where pebble-mounds are common.

Dunlop and Pound (1981) mapped the then known distribution of pebble mounds (Fig. 1). They had no records from coastal areas but showed that mounds were widely distributed through much of the Pilbara, Gascoyne and into the northern Murchison regions of WA (regional terminology is consistent with Thackway and Cresswell 1995). However, they concluded 'from the efforts of workers in the Gascoyne and Murchison districts it now seems probable that the species is extinct in these areas (Davies[2], personal communication) and the remaining populations may be confined to the eastern Pilbara'.

At that time, zoologists were alarmed by the extent of decline and extinction among Australian mammals. The patterns were not well understood but several Western Australian rodents were among the affected species (e.g. Ride 1970; Burbidge and McKenzie 1989; Lee 1995; Smith and Quin 1996). In view of the large, apparent contraction of range noted by Dunlop and Pound, *P. chapmani* was declared in 1983 by the State Minister to be 'fauna that is likely to become extinct or is rare' pursuant to the Western Australian *Wildlife Conservation Act 1950*. It was included in 'Part 2 - Species that are vulnerable' of 'Schedule 1 Listed Species' of the (Commonwealth) *Endangered Species Protection Act* and 'Vulnerable' by ANZECC (1991) but Lee (1995) treated it as 'Insufficiently Known'.

[2] S.J.J.F. Davies, formerly CSIRO, Perth, WA.

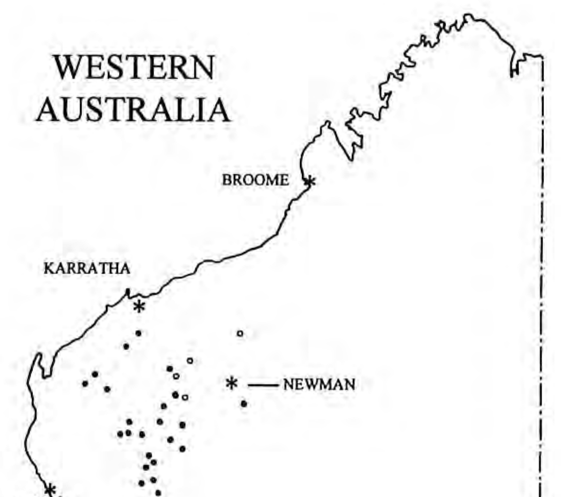

Figure 1. The distribution of pebble mounds known to Dunlop and Pound (1981). • = abandoned mounds; o = containing Ngadji.

Since 1980, many environmental assessments for proposed development projects have identified Ngadji on land that would be disturbed. The projects have been as diverse as highways, mines and their associated infrastructure (e.g. railways, construction camps and powerlines) and interpretive facilities (e.g. nature trails in national parks). Table 1 lists examples.

The first-generation of Pilbara iron ore mines and their associated infrastructure, including roads, railways and towns, were built between sixteen and eight years before *P. chapmani* was described; for example, Tom Price in 1964, Shay Gap and Pannawonica in 1972 (Anon 1979 p. 96). Nevertheless, much of the impetus and the resources used to acquire better knowledge of Ngadji in recent times have come from the iron ore mining industry. This has been encouraged by modern attitudes and obligations to environmental management, statutory environmental review procedures and the presence of a threatened species on so many second-generation project sites in the Pilbara.

The effects of developments on Ngadji came to the fore in the *Draft Environmental Review and Management Plan* for the Marandoo iron ore mine (O'Brien *et al.* 1992). The Ngadji was mentioned in 165 public responses of which 112 expressed concern about the effect of the project on its conservation status (Hamersley Iron Pty Ltd unpublished data). The proponent, Hamersley Iron (HI), made a commitment to determine the range and distribution of the species (O'Brien *et al.* 1992, p 232). Consequently, surveys of several key areas were conducted and voucher specimens have been lodged in the Western Australian Museum (Piggott 1992b, c, 1994d).

HI also established a detailed monitoring program at Marandoo (e.g. Hamersley Iron 1994) and supported research through The University of Western Australia. This work has focused on mound occupancy, movement patterns and social structure (Anstee 1994, 1996; Anstee and Needham 1997; Anstee *et al.* 1997a).

BHP Pty Ltd accepted commitments to manage and developed management programs for Ngadji at four Pilbara iron ore mine sites, Jimblebar, Yarri, Marillana Creek (Yandi) and Ore Body 18 (Piggott 1993a; Endersby 1994, 1997a, b; BHP Iron Ore and Ecologia 1996; Ecologia 1996a; Anon 1998). Consequent research and monitoring has yielded significant data on individual mice, their movements and mound activity as well as population structure, density and dynamics (e.g. Piggott 1993b, 1994a, b, c; Halpern Glick Maunsell 1997a, b, c, d, 1998c, d). These data are useful to those who have to manage the species at development sites. They also add substantially to knowledge of the biology of an Australian rodent that has adapted to a harsh, arid environment.

Implementation of the program at Marillana Creek (Yandi) mine site yielded information on (among other things) mound distribution and occupancy as well as the structure of the burrows and nest chambers under the mounds (e.g. Ecologia 1996b; Halpern Glick Maunsell

TABLE 1. Examples of Project proposals affected by the presence of. *P. chapmani.* Some projects have many pertinent references. The listed reference is the most detailed or the one that provides good directions to other documents.

PROJECT	TYPE	PROPONENT	REFERENCE
Area "C"	New iron ore mine	BHP	Piggott 1994a
Brockman Detritals	New iron ore mine	HI/CRA	Blandford *et al.* 1990
Burrup Land Use/Mgt Plan	Land use planning	State Government	O'Brien Planning Consultant 1994
Camel Road Heritage Trail	Nature trail	CALM	CALM files
Channar Mine	New iron ore mine	HI/CRA	Ninox 1985, 1986
Exmouth Borefield	Water supply	Water Auth. WA	Muir Environmental 1995
Jimblebar Mine	New iron ore mine	BHP	Ecologia 1996a
Marandoo Mine	New iron ore mine	HI/CRA	O'Brien *et al.* 1992
Mt Bruce Road	New road	Ashburton Shire	Main Roads WA 1995
Mt Whaleback	Mine management	BHP	BHP *in lit.* to CALM
BHP Ore Body 25	New iron ore mine	BHP	Ecologia 1995a
BHP Ore Body 18	New iron ore mine	BHP	Ecologia 1995b
Tom Price North Road	New road	Main Roads WA	Ecologia 1992
Yandicoogina Mine	New iron ore mine	HI/CRA	Hamersley Iron 1995
Yandicoogina Rail	New railway	HI/CRA	Hamersley Iron 1995
Marillana Creek (Yandi) Mines Stages 1 & 2	New iron ore mine	BHP	Ecologia 1996b
Marillana Creek (Yandi) Rail	New railway	BHP	Maunsell *et al.* 1988
Yarrie Mine	New iron ore mine	BHP	Piggott 1994a

1997e, f, 1998a). The latter complemented knowledge of burrow systems that had been obtained at Marandoo (Piggott 1992a).

Translocation offers a management option for Ngadji populations that would be destroyed by development, providing an opportunity to reintroduce them either to sites where they are locally extinct or to rehabilitated mine sites where they once occurred. There have been four experimental translocations. BHP management programs for Jimblebar and Ore Body 18 included translocations of Ngadji that would otherwise have been destroyed and showed that Ngadji can be translocated but the success rate was low (BHP Iron Ore Pty Ltd 1995; Ecologia 1996c, d, e, f; Halpern Glick Maunsell 1997g, 1998b). At Marandoo, no translocated animals are known to have re-established from a pilot translocation carried out on behalf of HI. A little red antechinus (*Dasykaluta rosamondae*, a dasyurid carnivore) was found carrying one of the translocated mice. It was dead. This predator may have killed several of them (Anstee 1995). HI has undertaken subsequent translocation projects using mice which would have been displaced by mining (Anstee unpublished data).

This work, augmented by numerous unpublished records of mounds and mice collected by other workers in the last ten years, has enormously increased knowledge of the species. The Ngadji is clearly much more widespread than Dunlop and Pound (1981) had realized and in many areas it is abundant in suitable habitat. It occurs in at least five large conservation reserves (Table 2).

Start (1996) collated the available information and reviewed the conservation status of the species. He recommended *P. chapmani* be allocated to the IUCN Species Survival Commission (1994) Red List category Lower Risk (Least Concern); no longer be declared by the Western Australian Minister for the Environment to be 'fauna that is likely to become extinct or is rare' and deleted from 'Part 2 - Species that are vulnerable' of 'Schedule 1 Listed Species' of the (Commonwealth) *Endangered Species Protection Act 1992*. These recommendations have been implemented (Western Australian Government Gazette 28 November 1997; Commonwealth Government Gazette 4 November 1998).

Most of the information that was available to Start was unpublished or contained in reports to HI or BHP. Like his review, it is generally unavailable to environmental managers and the scientific community. This is a significant handicap to biologists who are required to prepare environmental reviews and implement management programs involving Ngadji. Furthermore, the information in these documents adds significantly to our knowledge of Australian arid zone rodents. This paper aims to redress that situation. While all the reports we are aware of that contain information relevant to this mission are cited, some additional works are cited in Anon 1998. Finally, while we have not attempted a re-evaluation of Start's (1996) review here, our data support its conclusions and we believe the recommendations made in it were sound.

TABLE 2. The occurrence of *P. chapmani* in Western Australian National Parks and Nature Reserves.

CONSERVATION RESERVE	STATUS
Barlee Range Nature Reserve	Presence confirmed (Appendix 1)
Collier Range National Park	Presence confirmed (Appendix 1)
Karijini National Park	Presence confirmed (Appendix 1)
Millstream-Chichester National Park	Presence confirmed (Appendix 1)
Rudall River National Park	Presence confirmed (Appendix 1)
Carnarvon Range (proposed National Park)	Not surveyed but contains suitable habitat. *P. chapmani* is known from other upland areas of the Little Sandy Desert.
Mungaroona Range Nature Reserve	Not surveyed. Contains suitable habitat and is within its known range.
Cape Range National Park	Probably extinct

ISSUES THAT REQUIRED CLARIFICATION

Before Start (1996) could collate and review the data on Ngadji, he had to clarify several potentially confusing issues. For example, pebble mounds can provide useful evidence of the historical and present distribution of *P. chapmani* because they persist for a long time, even when occupants do not maintain them. Furthermore, occupied, 'active' mounds are readily distinguishable from unoccupied, inactive or 'old' mounds. However, evidence from mounds can only be used reliably if it is certain that *P. chapmani* has built them and, in the case of active mounds, is maintaining them.

Ngadji Mounds

In the Pilbara and adjacent regions, Ngadji pebble-mounds consist of accumulations of remarkably even-sized pebbles which may cover 0.5–9 m² (Dunlop and Pound 1981). They may be up to 0.5 m high (Piggott 1992a) but Anstee (1994) reported the mean dimensions of 25 mounds at Mt Bruce as 3.56 x 2.46 m by 0.12 m high with some exceeding 5 m on the longer axis. These are exceptionally large. Long-inactive mounds are usually raised above the ground surface but have a subdued profile and lack the 'topographic' features that characterize the surface of active mounds under which Ngadji are living. The features of active mounds include entrance holes to complex underground burrow systems and nest chambers up to 0.5 m below ground. The external entrances are often at the centre of cones and often blocked by pebbles (e.g. Piggott 1992a; Start and Kitchener 1995; Anstee 1996; Ecologia 1996b; Halpern Glick Maunsell 1998b). There is a published photograph of an active mound in Start and Kitchener (1995). Anstee (1996) gives a comprehensive description of the surface features and both he, Anstee *et al.* (1997b) and Ecologia (1996b), provide diagrams.

In the Pilbara and Little Sandy Desert, pebble mounds are built on slopes, commonly 2°–6°, composed of stony soils that usually have a hamada or surface stone-pavement. The soils are often shallow or skeletal and mounds are sometimes built around boulders or on the edges of exposed patches of bedrock. Typically, they are water run-off sites in a landscape characterized by sharply incised drainage lines. 'Hard spinifex', usually *Triodia basedowii* or *T. wiseana*, dominates the vegetation. *Eucalyptus leucophloea* or *E. gamophylla* are often present but other trees, mallees and a variety of shrubs, notably *Acacia* and *Senna* spp., may be present. The drainage lines support more floristically diverse and structurally complex plant communities that form linear thickets. *Acacia* is usually the dominant genus.

In the Hamersley and Ophthalmia Ranges, pebble mounds are common on the colluvial slopes that lie between massive, steep-sided ridges and their intervening river valleys and basins. These slopes were described and mapped as the Bahada Land Unit by Lorimer (1991). However, there and elsewhere, pebble mounds may also occur on weathered ridge tops and throughout landscapes composed of undulating uplands with a mantle of stony soils, as in parts of the Chichester Range. They do not occur on steep slopes, areas of bulky scree or areas devoid of stony soils and they are rarely present where the linear thickets marking drainage lines are absent.

Even in suitable habitat, pebble-mounds are not randomly scattered throughout the landscape and the density of pebble mounds varies across apparently similar habitat. For example, Piggott (1993b) found densities at Yarrie varied from less than one to three or four per hectare. At Shovelanna Hill in the east Ophthalmia Ranges, densities range from 0.06 to 0.2 mounds per hectare (Endersby 1997b). Furthermore, they are often grouped and frequently built near drainage lines. Endersby (1997b) and Piggott (1993b, at Yarrie) observed that mounds were frequently within 20 m of channels. Similarly, on Mt Bruce, Anstee (1994) found significantly more pebble-mounds within 21 m of the drainage lines than elsewhere (21 m = mean radius of core areas within home ranges, see below).

Large mounds contain many thousands of pebbles that the mice have excavated from the burrows below or gleaned from the surface nearby. Start and Kitchener (1995) reported that the weights of 1600 pebbles taken from 21 mounds in the Hamersley Range varied from 0.5 to 10 g each with 94 per cent weighing less than 5 g. The mode was in the 1.0–1.5 g size class. Dunlop and Pound (1981) recorded a range of 1.3 to 13.7 g in a sample of 73 pebbles. Figure 2 summarizes data on the weights of 300 pebbles from three Ngadji mounds at 23° 53'S, 120° 30'E, near Savory Creek in the Little Sandy Desert region (A.N. Start unpublished data).

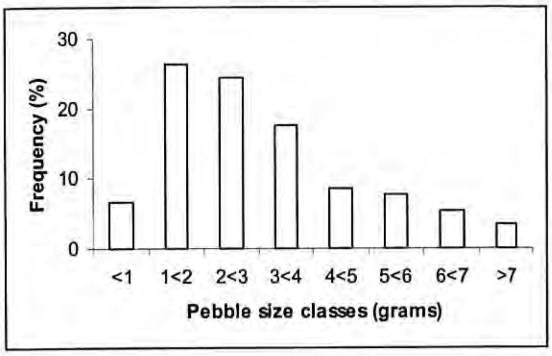

Figure 2. Weight classes (in grams) of pebbles taken from three Ngadji mounds at 23.88°S 120.50°E, near Savory Creek, Little Sandy Desert region, WA. N = 300: Range = 0.4 to 10.1: Mean = 3.06: SD = 1.83. 84% weigh < five grams.

Occasional larger pebbles (which may not all have been added by Ngadji) in samples can distort the impression for a reader who is not familiar with mounds in the field. In reality, Ngadji mounds are remarkable for the uniformity of pebble size. Davies (1986) noted 'the uniformity of their pebbles (is) such that they are used as screenings for concrete making by pastoralists.'

Other Mound Builders

In the upper Murchison, Davies (1986) recorded two types of pebble mounds distinguishable by pebble size. He ascribed one (pebbles weighing 1.5 to 3.8 g) to *P. chapmani* and the other (pebbles weighing 15.5 to 26 g) to 'an unknown larger murid', perhaps *Leporillus*. The large-pebble mounds tended to occur more commonly in the south but there was a broad area of overlap. He mapped (his Fig. 14) the positions of nine small-pebble mounds and five large-pebble mounds in an area approximately 150 x 150 m in a mixed colony on Erong Springs Station (25° 34'S, 116° 39'E).

In many areas stick-nest rats, *Leporillus* spp., incorporated stones in their nests. Stick-nest rats are now presumed extinct on mainland WA and surviving nests are degenerating. Many nests in sheltered caves and breakaways still contain sticks, stones and a black resinous material, 'amberat'. However, stick-nest rats often built in the open where the organic components of their nests have vanished leaving (where they incorporated them) piles of pebbles (Copley 1988).

Copley published photographs of several *Leporillus* pebble-mounds, including one in open mulga woodland in the Western Australian Goldfields (his Fig. 15) and he mapped the distribution of stick nests, distinguishing those containing stones from those that did not. Several sites where stones were incorporated occur within the former distribution of *P. chapmani*. Copley records the size of stones from the nests of *Leporillus* as 2–6 cm in diameter.

Figure 3 summarizes data on the weight of 21 pebbles taken from an old *Leporillus* nest. Their longest axes ranged from 18.5 to 50.0 mm (mean 31.7, SD 7. 7). The nest, which still contained some sticks and 'amberat', was situated in a small breakaway on Mulyajingle Peak (26° 11'S, 116° 07'E) in the Murchison. Although many of the pebbles were smaller than those recorded by Davies (1986), 76 per cent weighed more than 5 g whereas 84 per cent of the pebbles in the samples used to generate Figure 2 weighed less than 5 g. In our experience pebble-mounds derived from old *Leporillus* nests are readily, visually distinguishable in the field from those of Ngadji by the size of the pebbles, even where the former were built in the open.

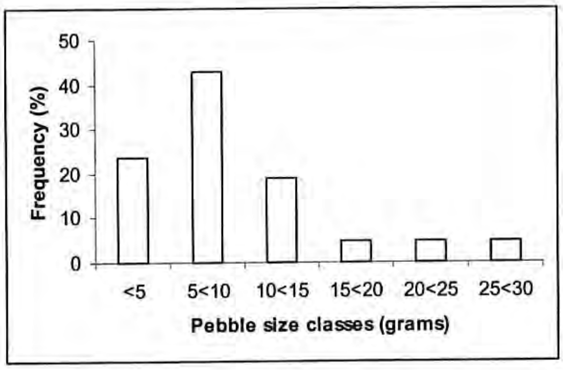

Figure 3. Weight classes (in grams) of pebbles taken from an old Leporillus *nest on Mulyajingle Peak, Murchison region, WA. N = 21: Range 2.8 to 25.1: Mean = 9.36: SD = 5.99. 76% weigh > five grams.*

Malleefowl, *Leipoa ocellata*, may have occurred in the extreme southern portion of the range of *P. chapmani* (compare Blakers *et al.* 1984 with Fig. 2) though Davies (1970) did not record Malleefowl from Mileura. Stones may incidentally be incorporated into Malleefowl mounds and it is possible that, where the organic components of old mounds have disappeared, pebble mounds may remain. Burbidge and Fuller[3] (personal communications) have noted several large pebble mounds, one of which was circular with a central depression, in a mulga community in the Gibson Desert. These may be the remains of Malleefowl mounds. However, pebble mounds derived from Malleefowl mounds are unlikely to be confused with those of Ngadji because the stones would not have been selected for size, apart from the exclusion of very large ones.

Since Dunlop and Pound (1981) discovered that *P. chapmani* builds pebble mounds in the Pilbara region, other species of mound-building mice have been recognized elsewhere in Australia. Ironically, *Pseudomys*

[3] Andrew Burbidge and Phil Fuller, Department of Conservation and Land Management, Western Australia.

patrius was associated with pebble mounds by Stalker who collected it in 1907 (Thomas and Dollman 1909) but it was overlooked by Lee (1995) and largely dismissed in the synonymy of *P. delicatulus* by other authors before van Dyck (1996) and van Dyck and Birch (1996) realized that it is the pebble-mound mouse of eastern Queensland where it occurs from near Townsville to near Gympie. Another, undescribed *Pseudomys* species builds pebble mounds in the Cloncurry - Mt Isa area of north-western Queensland. It is not *P. johnsoni*, as stated in van Dyck (1996) (van Dyck and Birch 1996, and van Dyck[4] personal communication).

Kitchener (1985) described *Pseudomys johnsoni* from specimens taken in 1983. It was known to Kerle (1995) from the Northern Territory in the Davenport and Murchison Ranges south-east of Tennant Creek and in a small area in the Barkly region but it is now known to be widespread and much more common than previously thought (Cole 1996).

Pseudomys calabyi was described as a subspecies of *P. laborifex* by Kitchener and Humphreys (1987) but Lee (1995), Woinarski (1992) and Woinarski *et al.* (1995) treat it as a full species. It has been recorded in association with pebble-mounds in the Northern Territory from Stage III of Kakadu National Park in the valleys of the upper South Alligator and Mary Rivers (Lee 1995). *P. laborifex* has not been reported to build pebble mounds but a pebble-mound mouse that occurs in the Victoria River District, Northern Territory (Woinarski[5] personal communication) and Gardner Range, WA (Coate 1995; A.N. Start, unpublished data) may be *P. laborifex* (Donellan[6] personal communication). Its taxonomic status is currently being studied.

There is an emerging pattern of Australian arid, sub-tropical, savanna uplands with stony surfaces being occupied by one or another of several small, pebble-mound building *Pseudomys* species. The five recognized species are isolated from one another by extensive areas of unsuitable habitat such as sandy deserts.

Because several species of *Pseudomys* build pebble-mounds, we considered the possibility that more than one species of pebble-mound mouse may occur in the Pilbara, Gascoyne, Murchison or Little Sandy Desert regions of WA. However, there is no evidence of this. Specimens of *P. chapmani* in the Western Australian Museum have been collected from almost all areas in which active mounds are recorded (Fig. 4 and Appendix 1). Although uplands containing mounds of pebble-mound mice are patchily distributed, there are few extensive, inhospitable land surfaces, such as sandy deserts, isolating any of the areas in which pebble-mounds occur. Perhaps the most isolated population lived on Cape Range, which is separated from other areas by a sand sheet. However, Baynes and Jones (1993) have identified sub-fossil material from there as *P. chapmani* while Baynes and Bradshaw (1996) have shown that sub-fossil material from coastal hills near Karratha is *P. chapmani*. A sand sheet also isolates the population at Yarrie. Nevertheless, specimens taken there are referable to *P. chapmani* (Cooper[7], personal communication).

Therefore, we assume that *P. chapmani* is the only pebble-mound mouse that occurs or occurred in those areas of the Murchison, Gascoyne, Pilbara and Little Sandy Desert biogeographic regions embraced by the distribution of mounds (Fig. 4 and Appendix 1).

Identifying Ngadji in the Field

Some of our records are based on mice that were trapped and released. Thus, reliability of field identification is an important issue. *P. chapmani* is usually caught near mounds (e.g. Dunlop and Pound 1981; How *et al.* 1991). Its size and/or other features can distinguish it in the hand from all other sympatric murids except *P. hermannsburgensis* (with which it has been confused in the past). Although *P. chapmani* and *P. hermannsburgensis* partition habitat (Halpern Glick Maunsel 1997h; ANS personal observation), there is a broad area of overlap and, at many sites, they can be caught together (e.g. Karijini National Park - Courtenay 1994; Jimblebar - Endersby 1994, Halpern Glick Maunsell 1997h; Ore Body 18 - Halpern Glick Maunsell 1998b; Marillana Creek (Yandi) - Halpern Glick Maunsell 1997e, f, 1998a; Yarri - Halpern Glick Maunsell 1997b, d; Packsaddle/The Governor area – A.N. Start unpublished data).

Kitchener (1980) distinguished '*P. chapmani* from all other species of the genus by a combination of its small size, large auditory bullae and short and broad palatine foramina'. The skull characters are useful for separating museum specimens. However it is not always appropriate, particularly with threatened fauna, to take specimens to access skeletal characters. *P. chapmani* and *P. hermannsburgensis* have similar pelage colour and body dimensions. Kitchener *et al.* (1984) showed that (for museum specimens) pes length plotted against ear length separated them. However, the groupings are contiguous and this ratio is not always adequate. In any case, field measurements on live animals are difficult, subadults confound the problem and Halpern Glick Maunsell (1997b, d) suggest that *P. chapmani* may be sexually dimorphic with discernible differences in field-measured head length.

Cooper (1993) described and illustrated differences in the footpads of the three small *Pseudomys* that occur in the Pilbara, including *P. chapmani*, *P. hermannsburgensis* and the superficially similar *Mus domesticus*. Since then, field workers have been able to identify live *P. chapmani* in the field (e.g. Anstee 1994; Courtenay 1994; Endersby 1994; Piggott 1994a; ANS personal observation). Confirmation of field identifications of animals deposited in the Western Australian Museum has verified the efficacy of the method (e.g. Piggott 1992b, c, 1994a, d; Endersby 1994).

[4] S. van Dyck, Queensland Museum, Brisbane.
[5] J.C.Z. Woinarski, Parks and Wildlife Commission, Darwin.
[6] Steve Donellan, South Australian Museum
[7] Norah Cooper, Western Australian Museum.

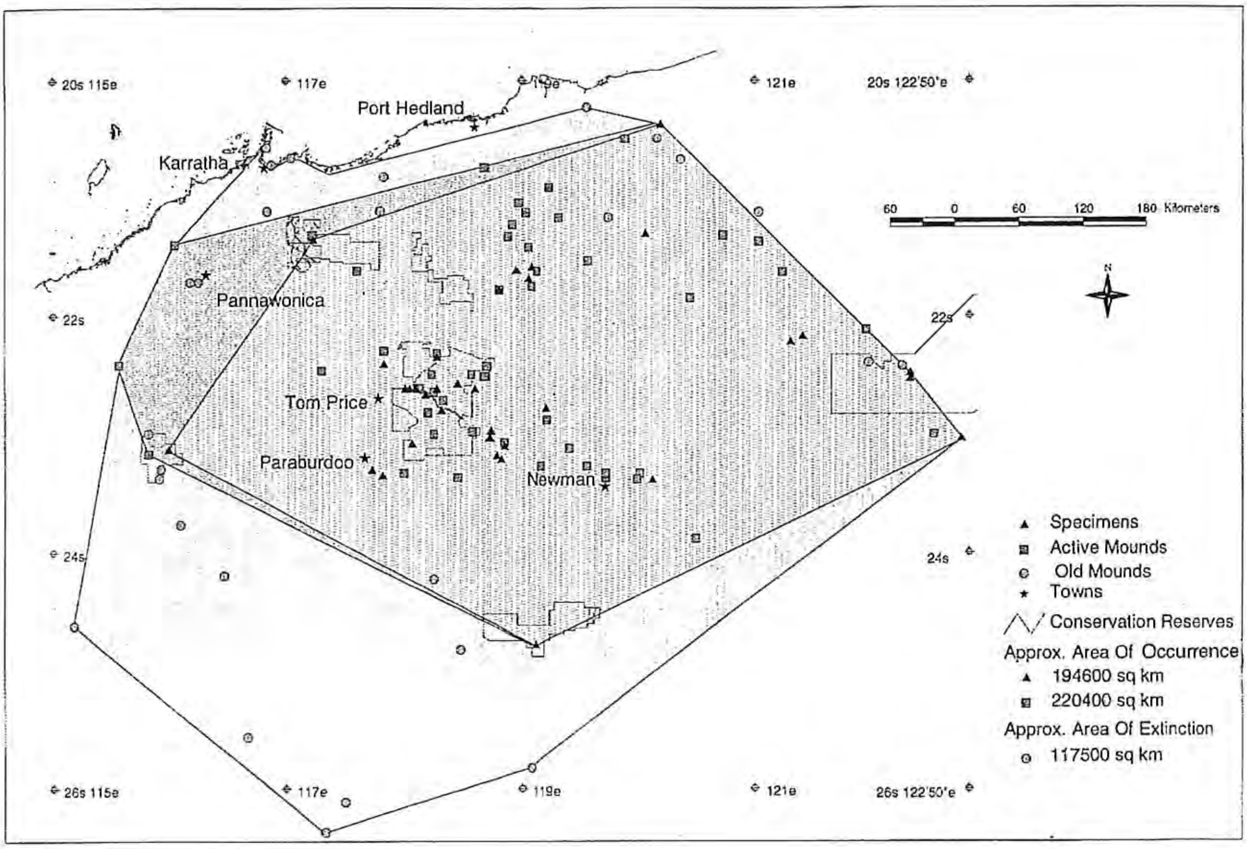

Figure 4. Past and present distribution of P. chapmani. *The figure presents three data sets with point locations for all records and convex polygons linking the peripheral locations in each data set to produce Extent of Occurrence maps (IUCN Species Survival Commission 1994). Note old mounds at one site on Cape Range not shown.*
The polygons depict:
Former Extent of Occurrence based on location of all mounds including old mounds (except one site on Cape Range)
Current Extent of Occurrence based on location of active mounds
Current Extent of Occurrence based on location of specimens

Associating Active Mounds with *P. chapmani*

It is understandable that pebble mounds were attributed to *P. hermannsburgensis* before *P. chapmani* was recognized as a distinct species (e.g. Ride 1970; Watts and Aslin 1981). After all, specimens in the Western Australian Museum identified as *P. hermannsburgensis* had been taken from pebble mounds (Kitchener 1980). Even after that, Dunlop and Pound (1981 p. 2) state '*P. chapmani* builds pebble mounds and *P. hermannsburgensis* merely uses these nests in the Pilbara on an opportunistic basis'. Their assertion that *P. hermannsburgensis* uses the pebble-mounds opportunistically continues to be cited, although not always referenced (e.g. Kitchener 1983; Ecologia 1995a, b, 1996a).

The experience of most workers over the last eight years is that active mounds are reliable indicators of extant Ngadji. Where there are active mounds, *P. chapmani* can invariably be caught, given sufficient effort. Furthermore, we have not been able to locate any original records of *P. hermannsburgensis* occupying pebble-mounds let alone building or maintaining them. A considerable body of circumstantial evidence suggests that they do not do so although they may be caught close by and, at Ore Body 18, four male *P. hermannsburgensis* and one female *P. chapmani* were caught within a flywire hoop erected around an active pebble-mound (Halpern Glick Maunsell 1998b).

Ngadji are not easily trapped and most workers place Elliott traps inside fly-wire fences encircling active mounds (Anstee 1994). This method is particularly useful for catching all the occupants of a mound where the number of mice per mound is to be recorded (e.g. Anstee 1994; Piggott 1994a; Ecologia 1996c; Anstee *et al.* 1997a,b; Halpern Glick Maunsell 1997d, 1998a,) or where all mice are to be removed prior to earthworks commencing (e.g. BHP Iron Ore Pty Ltd 1995; Ecologia 1996b; Halpern Glick Maunsell 1998b).

Other mammals are seldom reported from within the fences. The House Mouse, *Mus domesticus*, has been caught within them at Marillana Creek (Yandi) (Ecologia 1996g), Marandoo (Anstee, unpublished data), Mt Whaleback (Endersby, unpublished data) and Jimblebar, where released House Mice ran straight to burrow openings on the mounds and entered them (Teale[8] personal communication).

A small dasyurid, *Ningaui timealeyi*, was the only other mammal caught within fences at Marillana Creek (Yandi) where 77 *P. chapmani* were recovered from 43 of 65 active mounds. *N. timealeyi* and two other dasyurids, *Dasykaluta rosamondae* and *Sminthopsis* sp. were caught within fences at Marandoo. Courtenay (1994) caught another rodent, *Zyzomys argurus*, at an active mound in Karijini National Park but she was not using encircling fences and there is no evidence that it was using the mound. Piggott (1994e p. 266) observed that 'occasionally other species do "invade" mounds' but gave no supporting evidence.

The House Mice may have been living in burrows beneath pebble-mounds but Ningaui, which are known to shelter in spinifex hummocks (Dunlop 1995), were probably living above ground, albeit within the fences. *D. rosamondae* preys on *P. chapmani* (Anstee 1995) but it is uncertain whether it, or the *Sminthopsis* sp, were sheltering in the Ngadji burrows. In any case, the dasyurids are unlikely to tend them.

P. hermannsburgensis occurs in all these areas but has only once been caught within the fences (Halpern Glick Maunsell 1998b). Indeed, at Jimblebar where there was a trapping grid in addition to traps set at fenced mounds, *P. hermannsburgensis* was sometimes caught more frequently than *P. chapmani* in un-fenced traps on the grid, but was never caught within fences (Roy Teale personal communication).

Over much of the range of *P. hermannsburgensis* (Breed 1995) there are no pebble mounds (e.g. Ride 1970; Dunlop and Pound 1981; Watts and Aslin 1981) suggesting that it does not build them. Furthermore, there are numerous places where old pebble mounds show no signs of being used, even where *P. hermannsburgensis* is still present. This suggests that *P. hermannsburgensis* does not tend mounds abandoned by Ngadji. Similarly, House Mice are often common where pebble-mounds are now abandoned, suggesting that, even if they co-habit mounds with Ngadji, they do not maintain the mounds after the pebble-mound mice have gone.

We conclude that in these areas, only Ngadji build and tend pebble-mounds attributable to small murids.

Classifying Mound Activity

Many of our records are based on the presence of 'active' mounds. Thus the ability to determine whether mounds are still active is crucial. In 1988, Start (unpublished) sprayed non-toxic, water-based paint on pebble mounds to determine whether they were in use: Ngadji moving pebbles expose unpainted surfaces which are easily observed the next day. Several workers have used the method since. It has been useful in identifying occupied mounds and demonstrating that some mounds are used each night while others are used intermittently (see below).

However, visual methods are often used to identify active mounds and several classifications for the level of activity have been developed. Endersby (1994) used four categories, one active and three inactive (indicating different time frames since mounds were abandoned). Studies by Ecologia (1996c, d, e, f, g, h) and Halpern Glick Maunsell (1997d, f, 1998b) for BHP have used Endersby's classification. Piggott (1992d) used three categories, 'active', 'inactive' and 'old' and used the 'paint test' to subdivide 'active' into 'in use' or 'not in use'. Anstee (1994, 1996) developed a visual scoring method to determine the likelihood of *P. chapmani* presence in mounds. It is based on an activity index derived by scoring each of three mound features on a 0–3 scale. His method circumvents the constraints imposed on trap effort by time and resources, and possible errors inherent in the paint test (mice may be deterred by paint and other animals may disturb mounds). Courtenay (1994) used the paint test but distinguished 'movement' (pebbles had been turned so that paint was hidden) from 'activity' (unpainted pebbles appeared on the mound surface).

Because a variety of systems have been used, in this paper we use two categories of activity where we address issues of distribution and decline. They are:

'Active' where it is clear that a mound is being tended and

'Old' where mounds are clearly abandoned.

THE CURRENT STATUS OF *P. CHAPMANI*

Distribution

Figure 4 plots the current and inferred-recent (probably post-European settlement) distribution of *P. chapmani* using pebble mounds, and live animals. The map distinguishes sites at which only old mounds have been recorded (and the species is presumed to be locally extinct) from sites at which Ngadji have been caught or where active mounds have been recorded since 1980 (and the species is extant). The Extent of Occurrence[9] indicated by each data set has been calculated from convex polygons created by joining the peripheral locations (IUCN Species Survival Commission 1994). The plots and area calculations were generated with the GIS package ARCVIEW Version 2.1 (ESRI 1994).

Almost all areas where Ngadji were recorded between 1980 and 1990 have been revisited since then so that data on the presence of Ngadji and active pebble mounds are mostly no more than eight or nine years old. The concentration of records between Tom Price and Newman reflects the extensive occurrence of iron ore deposits in the

[8] Roy Teale, Halpern Glick Maunsell, Perth.

[9] The terms Extent of Occurrence and Area of Occupancy are defined in IUCN SSC (1994).

Hamersley and Opthalmia Ranges and consequently the location of work done by iron ore mining companies. Similarly, the concentration of active mound records south-east of Port Hedland reflects field work by J.N. Dunlop and C. Newland who recorded mounds while inspecting gold mining projects in that area. They did no trapping.

Although Ngadji are common in those two areas, they are not necessarily the areas of greatest abundance. Many of the gaps reflect lack of fieldwork rather than absence of Ngadji. For example, there have been no biological surveys in the Chichester, Collier or Mungaroona ranges. The Ngadji records from Millstream-Chichester, Collier Range, Parry Range and Rudall River National Parks were obtained during brief visits made specifically to search for *P. chapmani* (Piggott 1992b, c, 1994d). Furthermore, pebble-mounds are easily 'missed' where people do not search specifically for them.

Huge areas of potentially suitable habitat have not been examined, particularly in the Chichester Range and the Hamersley Range west of Tom Price. From the air, there appear to be extensive areas of suitable habitat in Mungaroona Range Nature Reserve and many other parts of the Chichester Range (ANS personal observation). However, it should also be noted that there are large areas of unsuitable habitat within the Extent of Occurrence of *P. chapmani* (e.g. alluvial surfaces of the Fortescue River valley, large mulga flats in the south-east Pilbara and sandy surfaces in the Little Sandy Desert).

There is close correspondence between the area from which there are specimens and that where active mounds are known to occur. Inclusion of the large area in the west, where there are no specimens to support records of active mounds, is based on pebble-mound records of Piggott (1994d) in the Parry Range and Dunlop in hills south of the Fortescue River near the North-west Coastal Highway (Dunlop[10] personal communication; and maps held by the Department of Minerals and Energy, Karratha). Neither observer trapped at these sites.

Changes in Distribution

We consider that a population of Ngadji comprises a group of individuals that are readily able to encounter and interact with other members of the population. Discrete populations are separated by landforms that are not normally occupied by Ngadji so that interaction between members of adjacent populations is infrequent to impossible (e.g. sand plains, broad river valleys). No Ngadji populations are known to have disappeared since 1980. Figure 4 shows that the original Extent of Occurrence was about 340 000 km^2. Ngadji still occur in suitable habitat within 220 400 km^2 (65 per cent) of that area. They seem to be extinct within about 13 000 km^2 of the Pilbara's coastal lands and 104 000 km^2 of the upper Murchison, and the Gascoyne, although Coate (1997) has recently reported and published a photograph of active mounds on Mt Phillip Station (24° 24' S 116° 18' E) in the Gascoyne, suggesting that at least one relict population may survive there. However, there is proportionally much less suitable habitat on the Pilbara coast, and areas of the Murchison and Gascoyne from which Ngadji have disappeared than in the uplands of the Pilbara. Thus, the decline in Area of Occupancy is probably substantially less than 35 per cent of the original area.

The status of Ngadji on Cape Range is unclear. They are known from sub-fossil deposits (Baynes and Jones 1993) and mounds have recently been reported (Muir Environmental 1995). Muir considered that one mound may have been active but several others were old (Muir[11] personal communication).

The areas in which Ngadji persist correspond closely with the areas mapped by Beard (1975) as hummock grasslands. This accords well with Ngadji habitat summarized by Start and Kitchener (1995). Even in the eastern Hamersley Range, where Beard maps extensive areas of mulga woodland interspersed with hummock grasslands, the woodlands mostly occupy sites that are low in the landscape, often on extensive clay or loam flats. The intervening uplands are stony ridges, usually dominated by hummock grasses (van Etten 1987). Pebble-mounds are largely absent from the flats (where *P. hermannsburgensis* is commonly caught) but abundant on the uplands (Halpern Glick Maunsell 1997h; A.N. Start, unpublished data). The records from the Collier and Barlee Ranges were also from habitats dominated by spinifex (*Triodia* spp.), although much of the surrounding country carries mulga woodlands.

Beard mapped that portion of the Gascoyne and Murchison from which Ngadji have apparently disappeared as low woodland of mulga (*Acacia aneura*) or scrub of *Acacia* and other species, or low scrub of *Eremophila* and *Senna* species (he used the generic name *Cassia*; for a discussion of *Cassia* and *Senna* see Randell 1988). Hummock grasslands are scarce, even on uplands where shrubs, particularly *Senna* and *Eremophila* species, are common components of the mulga understorey or (on very shallow soils of uplands) the dominant genera. Mabbutt (1963) provides more detail on the land units at Mileura where Davies worked.

In this region, pebble mounds usually occur on the slopes of hills and ridges dominated by *Senna* species (Davies[12] personal communication; Coate 1997). Coate described the terrain where he observed active mounds on Mt Phillip Station as 'flat with gentle slopes'. The mounds were 'close to drainage systems' and the vegetation was 'mainly of *Acacia* species (*Acacia aneura* prominent along the creeks), *Eremophila* species and *Senna* species'.

The coastal Pilbara mostly comprises plains vegetated by a mosaic or mixture of hummock and bunch grasses. On the Abydos Plain, east of Whim Creek, the soils are mostly sandy and on the Roebourne Plain, west of Whim Creek, soils are finer grained clays or loams. These plains do not offer suitable habitat for Ngadji but, in places, there are small ranges on which old pebble-mounds have been recorded. These include hills east of Port Hedland, near

[10] J.N. Dunlop, Department of Minerals and Energy, Karratha, WA.

[11] B.G. Muir, Muir Environmental Consultants. Perth WA.

[12] S.J.J.F. Davies, formerly CSIRO, Perth, WA.

Whim Creek, Wickham, the Burrup Peninsula and hills to the south of Karratha. They carry hummock grasslands and have patches of suitable, stony slopes.

It is difficult to determine when Ngadji disappeared from the upper Murchison, much of the Gascoyne and coastal areas of the Pilbara. In his account of the fauna and flora of Mileura Station in the decade 1960–1969, Davies (1970) wrote 'the old nests – survive on Mt Hale'. Thus it had probably gone from there at least 40 years ago, perhaps much earlier. Piggott (1994d) reported that the owner of Mulgul Station, who had lived his life in the area, still sees old mounds but had not seen any active mounds for 20 or 30 years.

In coastal sites Butler and Butler (1983) caught *P. hermannsburgensis* and reported active mounds on the Burrup Peninsula (they attributed the mounds to *P. hermannsburgensis* despite Kitchener (1980) and Dunlop and Pound (1981) showing that *P. chapmani*, not *P. hermannsburgensis* was the pebble-mound mouse in the Pilbara). However, numerous naturalists and biologists have worked there since and we can find no other reports of active mounds or live Ngadji (e.g. O'Brien Planning Consultants 1994; Kendrick[13] personal communication; ANS personal observations). Mounds in the hills just south of Karratha lacked any surface relief and appeared very old in 1979. Their appearance had changed little by 1995 suggesting that they could have been inactive since the late 1960s and perhaps much earlier (A.N. Start unpublished data).

CAUSES OF THE DECLINE

Smith and Quin (1996) reviewed the patterns and causes of decline and extinction in Australian conilurine rodents. They note that most declines occurred before 1970 and that 69 per cent of 16 Eremaean species (they had insufficient data for the others) have experienced large range contractions. Although they found many univariate correlations between patterns of decline and a variety of factors, they point out that interpretation of univariate associations could result in misleading conclusions. Confounding interactions between various factors have to be taken into account. Dickman *et al.* (1999) demonstrate that densities of many arid Australian rodent populations reflect recent rainfall histories, but that other factors including fire and predation by foxes and cats may modify expected responses to rainfall events.

Rabbits

Declines of conilurine rodents have been most severe where rabbits have been abundant (but there are several interacting factors including rabbit-caused habitat degradation, support of exotic predator populations, etc.). However, rabbits are absent from most of the historic range of Ngadji (compare King 1990 with Fig. 4) and, where present, they probably occupy different habitat to that of Ngadji. For example, rabbits are present in small numbers in the south-east Pilbara and Little Sandy Desert where they occupy mulga flats or claypans, habitats not used by Ngadji (A.N. Start unpublished data).

Foxes

Even where rabbits are scarce or absent, declines of conilurine rodents have been severe where foxes and/or livestock have been abundant and circumstantial evidence suggests foxes may have been instrumental in the local extinction of Ngadji. Foxes were first reported in WA 160 km west of Eucla in 1915. The first bounties on scalps from the Pilbara (Roebourne and Nullagine) were paid in 1931 but foxes were present in the Gascoyne and Murchison some years earlier (Long 1988). Long reported foxes to be common on the upper west and lower north-west (= the Gascoyne and Pilbara) coasts but rare in the Pilbara uplands and now uncommon in the mid-west interior.

King and Smith (1985) present data from bounty returns that indicate fox numbers peaked between 1928 and 1935, soon after they arrived in the Northwest Division (i.e. pastoral areas from the Eighty Mile Beach to the agricultural lands of the Southwest Division, including the whole of the Ngadji's original range). In 1930 about 30 per cent of 11 038 Western Australian bounties were paid on foxes from that Division despite a relatively small human population able to take them.

King and Smith also examined the distribution of foxes in WA. In Figure 5, their data for the area encompassing the Extent of Occurrence of Ngadji is superimposed on the distribution of pebble-mounds. There is a close similarity between the areas where they had numerous fox records, the Murchison and Gascoyne and the Pilbara coast, and the areas where *P. chapmani* has declined. However, they obtained very few fox records from the non-coastal areas of the Pilbara where Ngadji remain widespread and often common. Those they recorded were from:

- Yalleen, Millstream, Coolawanyah, Hooley, Mulga Downs, Roy Hill and Ethel Creek pastoral leases which all lie on the Fortescue River. Foxes may have followed the river valley which supports bunch grass, saltmarsh and riparian woodland communities (Beard 1975) that Ngadji do not occupy.
- Yarrie and Warrawagine pastoral leases on the De Grey River. Again foxes may have followed a large river, but there are extensive areas of sandy soil, which Ngadji do not occupy. They also record foxes from pastoral leases with sandy soils on the Abydos Plain.
- Juna Downs, Sylvania, Prairie Downs, Weelarrana and Turee Creek pastoral leases in the south-east Pilbara where there are extensive areas of mulga woodlands that are similar to the woodlands which cover much of the Gascoyne and upper Murchison country in which fox records have been numerous. Even so, foxes are apparently rare on these pastoral leases now (personal communications from several pastoralists) and pebble mounds have only been recorded on stony uplands carrying hummock grasses that are embedded in the mulga landscape.

[13] Peter Kendrick, Department of Conservation and Land Management, Western Australia.

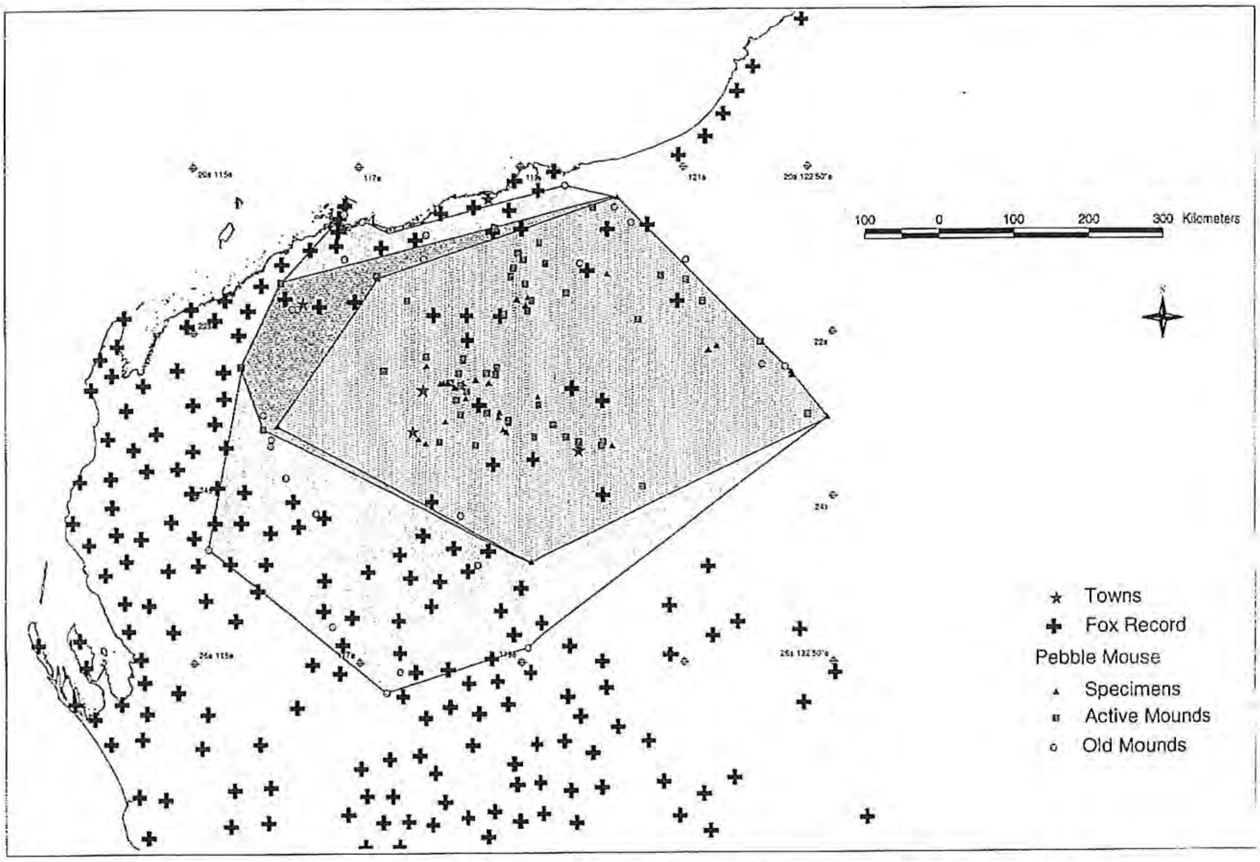

Figure 5. Distribution of foxes in relation to the former and current Extent of Occurrence of P. chapmani. *Data on foxes were obtained from King and Smith (1985). For an explanation of the distribution of* P. chapmani *see Figure 2 caption.*

The fox presence/absence data of King and Smith do not reflect abundance. Anecdotal evidence supports Long's (1988) assertion that foxes are rare in the Pilbara uplands, even on the Fortescue River. Thus, at Millstream (which is on the Fortescue), National Park Rangers did not report any foxes between 1979 and 1988 (Department of Conservation and Land Management files) and none have been seen by the Ranger-in-Charge since then (Geoff Kregor personal communications). Discussions with pastoralists and 'doggers' during those years indicated that foxes were rarely sighted or caught in dingo traps and sightings were memorable (A.N. Start unpublished data). Long-time residents of the Pilbara's inland pastoral areas reported that most of their fox sightings dated back several decades and they rarely see foxes these days (Peter Kendrick personal communication). There have been no reports by rangers of foxes in Karijini National Park during the past 20 years.

Foxes are still common on the Pilbara coast where their predation is the most likely cause of decline or extinction of rock wallaby populations. Kinnear *et al.* (1998) has demonstrated the ability of foxes to depress or eliminate rock wallaby populations. On the Burrup Peninsula and Dolphin Island, rock wallaby (*Petrogale rothschildi*) numbers increased substantially after fox baiting (Kinnear[14] personal communication). On Depuch Island near Whim Creek, there was widespread evidence of foxes eating rock wallabies (*Petrogale lateralis*) in 1962 (Ride 1964). That population of rock wallabies is now extinct.

Cats

Smith and Quin (1996 p. 17) implicated cats as 'the primary agents of decline among the smaller (10–90 g) conilurines and among conilurines of all body sizes in areas where dingoes are abundant and foxes are scarce or absent'. They found that where rabbits and foxes are scarce (but dingoes may be abundant), cat abundance is the best predictor of decline in small conilurine rodents. Cats occur throughout Australia and preceded foxes into many areas (e.g. Burbidge *et al.* 1988; Burbidge and McKenzie 1989; Wilson *et al.* 1992; Smith and Quin 1996). Few environmental factors limit their distribution; they do not have to drink fresh water and they reproduce in all habitats but they are very cryptic and often go unseen (Wilson *et al.* 1992). Martin *et al.* (1996) reported that native rodents were the most frequent item (16 per cent) in the stomachs of cats taken in the pastoral areas of WA. Their sample of 53 cat stomachs was mostly obtained from the Pilbara and Murchison regions in 1992–94. Cat population densities in the current range of Ngadji are unknown but they are certainly present and they have obviously not caused a significant decline in the distribution of Ngadji although they may affect Ngadji population densities and may have caused some local extinctions. The impact that cats may have had in other parts of the former range of Ngadji is not known. They may well have exacerbated the effects of foxes and exotic herbivores in the Murchison and Gascoyne and of foxes on the Pilbara coast.

[14] J.E. Kinnear, Department of Conservation and Land Management, Perth.

Livestock and Other Exotic Herbivores

With the exception of locations in the Little Sandy Desert, the historic range of Ngadji lies within the pastoral zone. However, a substantial portion of their range in the Pilbara is in uplands which, being of little pastoral value, have remained vacant Crown land or been reserved, often for national park or nature reserve. Where Ngadji occur on pastoral leases, their usual habitat of upland, run-off sites with shallow, stony soils supporting 'hard' spinifex is generally avoided by cattle and sheep. Goats are absent and donkeys occur sporadically. Where they are present, donkeys, like stock, usually seek more hospitable and productive sites. Therefore, there is little disturbance of Ngadji habitat by exotic herbivores in the Pilbara.

However, in the mulgalands of the Gascoyne and northern Murchison, exotic herbivores have not avoided Ngadji habitats. Stocking rates with sheep and/or cattle have been very high in relation to the carrying capacity, and degradation of the country is widespread and sometimes very severe (see Hobbs and Hopkins 1990 for an overview). Furthermore, goats have been numerous through much of the area (Wilson *et al.* 1992) and have exacerbated the degradation of the land and vegetation.

Fire

Fire is often thought to affect the status of mammals in arid Australia (e.g. Burbidge and McKenzie 1989). Much of the debate has focused on changes in fire patterns since the pattern of Aboriginal peoples' occupation of the land, and consequently their burning practices, have changed. However, there is little information on fire responses by arid Australian rodents (Sutherland and Dickman 1999). The spinifex habitats of Ngadji in the Pilbara are fire-prone and probably burn frequently because the spinifex hummocks provide excellent fuel. Lightning and Aboriginal people lit fires before European settlement but the frequency, intensity and spatial extent of fires in the Pilbara have probably changed since Aboriginal people left the land (e.g. Start *et al.* 1991). Pastoralists and the managers of Crown reserves including national parks and nature reserves have assumed responsibility for fire management while large areas that remain vacant Crown land are effectively unmanaged. Yet Ngadji persist in their spinifex habitats across tenure types and mounds are still actively tended after fires have removed surrounding vegetation (Halpern Glick Maunsell 1998c; A. N. Start unpublished data).

In November 1997 a wild fire burnt some or all of the vegetation (dominated by hummock grass) on nine of ten monitoring plots and two research plots at Yarrie. The research plots (on which 65 per cent and 95 per cent respectively of the vegetation was destroyed) were monitored about five weeks after the fire. Mound activity was lower than in previous summers and, unusually, no females were breeding. However, Table 6 shows that the estimated total population of mice was higher than it had been through 1996 and early 1997 (Halpern Glick Maunsell 1998c). It is difficult to determine the significance of the quantitative shift in relation to fire because the bait in traps may have been more than usually attractive after the fire when food may have been scarce. Nevertheless it is clear that a relatively dense population coped well with the initial post-fire period.

Western Australian mulga woodlands without spinifex or other highly flammable understorey species are relatively infrequently burnt (Start 1986; van Leeuwen *et al.* 1995). However, this is the habitat that covers most of the country from which Ngadji have disappeared in the Gascoyne and Murchison. As Ngadji have persisted in the more fire-prone habitat it seems unlikely that fire has been a significant, causative factor in their decline.

CONCLUSION

We conclude that circumstantial evidence suggests the areas from which Ngadji have disappeared correspond well with areas where foxes have been abundant and/or widespread. Except on the Pilbara's coastal hills, it also corresponds with the habitats grazed by livestock and feral herbivores. The latter process may have exacerbated fox predation by allowing 'hyperpredation' (Smith and Quin 1996). The effect of cat predation is unknown, but it may have exacerbated the effects of foxes and ungulates. Fire has probably not been a significant causative factor.

MOUND OCCUPATION

Since Ngadji expend considerable amounts of energy building and tending pebble mounds on stony uplands, the mound must confer an advantage not used by or not available to species living in other parts of the same landscape. A plausible hypothesis proposes that the mound insulates nests from extremes of temperature where frosts and very high temperatures are common and shallow stony soils prohibit deep burrows (Anstee 1994 in Appendix 4). There has been only one study comparing temperatures outside the nests with those inside. Piggott (1994a) reported nest temperatures fluctuating between 19°C and 25°C while surface temperatures varied from 6°C to 36°C over a 24-hour period in August.

Pebbles are an appropriate material from which to build the mounds because:

- they are abundant in Ngadji habitat
- their mass and hardness makes them more resistant to wind and water erosion than soil
- organic materials would be a liability in fire-prone hummock grasslands and pieces small enough for the mice to carry would be susceptible to erosion and decay
- wind-blown sand and dust is trapped between the pebbles adding to their insulating effectiveness at no additional energetic cost to the mice. Spaces between pebbles below the near-surface layers are usually filled by sand or soil particles (A.N. Start unpublished data).

However, construction of a new mound by each individual or pair entering a population would be energetically and temporally expensive if not prohibitive and new mounds are rarely observed. Endersby (unpublished data) noted two new mounds at Jimblebar in 1994 but has seen none since then. Where mound activity has been monitored for several years at Yarrie (since 1993) and at Marillana Creek (Yandi) (since 1995) no new mounds have been recorded and we are not aware of new mounds being recorded anywhere else except where mice have been enclosed with piles of pebbles.

Communal construction and occupation of mounds by successive generations of mice would be an energetically economical strategy for animals that live under huge pebble-mounds.

There is evidence that successive generations of Ngadji occupy mounds. Some mounds are known to have been active for over 20 years (A.N. Start, unpublished data), much longer than the expected life span of small Australian murids (Predavec 1997). Furthermore, at many sites most mounds are active. For example, at Yarrie, 232 (77 per cent) of 300 mounds were active (Piggott 1993b). This is more likely to reflect long-term occupation of mounds by successive generations than recent colonization or population expansion because:

- there are some inactive mounds with very subdued profiles that have probably not been used for several decades. They indicate that Ngadji have been at the site for at least that long
- almost all active mounds observed in 1993 are still tended by Ngadji. (We have no data on whether the untended mounds have been abandoned altogether.)
- no new mounds have been observed on monitored plots despite times when the number of ngadji in the population has increased (e.g. at Yarrie and Marillana Creek (Yandi), Table 6).

Ngadji often live gregariously. Although it is common to catch only one mouse from a mound, multiples are frequent (Table 3) and the occupants of a mound may comprise adults of both sexes as well as juveniles (e.g. Anstee *et al.* 1997b). Twenty-five were taken from one mound surrounded by fly-wire at Jimblebar (Ecologia 1996c): however, that is exceptional. Data are available from 192 active mounds that were encircled with fly wire and trapped. A total of 424 mice were trapped at 145 (75.5 per cent) of them to give a mean of 2.92 mice per occupied mound. Figure 6 shows the distribution of mouse numbers per mound.

Observations on captive colonies provide further evidence that Ngadji can live and reproduce when many animals cohabit. Thus, young have been born and raised in a colony of 15 adults at the Perth Zoo (Bradley[15], personal communication). CALM[16] held two captive colonies in which several mice were housed amicably and bred in large terraria part filled with pebbles. In one, following collapse of part of a burrow, the mice transferred three litters of infants that had been born 'underground' into a depression that they constructed in the surface pebbles. Thereafter, all three mothers and an adult male spent their days asleep in a huddle over the infants.

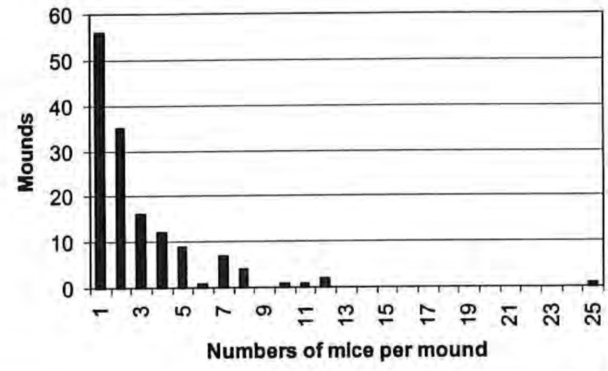

Figure 6. Numbers of mice per mound caught within fly wire fences erected around 192 active pebble-mounds. Data compiled from Anstee (unpublished data), Ecologia (1996b,c,i), Halpern Glick Maunsel (1997b,c,d,e,f, 1998a,b) and Piggott (1992a).

The number of Ngadji occupying a mound fluctuates with time. Table 4 illustrates changes in the number of mice caught at mounds over longer periods. This could be explained by nomadic movement of mice between mounds or by fluctuations in the number of animals in the population. The latter seems more likely because there is evidence that individuals have a home mound to which they return regularly. Halpern Glick Maunsell (1997a, c, 1998c) captured one male Ngadji at the same mound three times over a period of 16.5 months between August 1996 and December 1997. Anstee (1994) and Anstee *et al.* (1997b), found that radio-collared animals always returned to the same home-mound for the day. Core areas around home-mounds were used by residents but not by mice from neighbouring home-mounds. However, mice from several home-mounds shared home ranges beyond their core areas.

At Anstee's study area, surplus mounds (that did not have daytime occupants) were frequently visited during the night and mice from more than one home-mound would visit the same surplus mounds. The visitors would enter burrows and move pebbles on the mounds. Collective tending of surplus mounds may explain why it is common to catch no mice at some apparently active mounds and why several studies have found that some mounds are used each night while others are used intermittently (Piggott 1994a; Chapman 1995; Ecologia 1996i; Halpern Glick Maunsell 1997c, e, f, 1998a, d).

REPRODUCTION

Table 5 contains data on the reproduction of Ngadji. Pregnant Ngadji have been recorded in every month except January and April. There is no evidence that pregnancies do not occur in January and April; rather data on

[15] Mark Bradley. (Former) Director of Research, Perth Zoo.
[16] The Western Australian Department of Conservation and Land Management.

TABLE 3. Numbers of *P. chapmani* trapped within fences encircling active mounds. Only data from sites at which more than 40 mice were trapped are included.

LOCATION	ACTIVE MOUNDS TRAPPED (WITH MICE)[a]	NUMBER OF MICE PER MOUND (2/14=2 MICE IN EACH OF 14 MOUNDS)	TOTAL MICE CAUGHT (MEAN)[b]	REFERENCE
Jimblebar	10 (8, 80 %)	0/2, 1/2, 2/1, 5/1, 7/1, 8/1, 10/1, 25/1	59 (7.4)	Ecologia 1996c
Mt Bruce	32[c] (25, 78 %)	0/7, 1/7, 2/5, 3/1, 4/1, 5/3, 6/1, 7/2, 8/2,11/1, 12/2	110 (4.4)	Anstee unpublished
Marillana Creek (Yandi)	72 (52, 72 %)	0/22, 1/30, 2/14, 3/2, 4/2, 5/1	77 (1.5)	Ecologia 1996b
Yarri 1	9 (9, 100 %)	2/1, 3/1, 4/4, 5/1, 7/1, 8/1	41 (4.6)	HGM[d] 1997d
Yarri 2	17 (13, 76 %)	0/4, 1/1, 2/3, 3/6, 5/1, 7/2	44 (2.7)	HGM 1998c

[a] Numbers in parentheses = active mounds containing at least one mouse.
[b] Numbers in parentheses = mean number of mice per mound in mounds containing at least one mouse.
[c] Anstee actually trapped at 16 active mounds but re-trapped some at 3 or 9 month intervals to give 32 mound-trap sessions (see Table 4).
[d] HGM = Halpern Glick Maunsel.

TABLE 4. Variation with time in the number of *P. chapmani* trapped at two adjacent study sites, Mt Bruce (MB) and Marandoo (M). nt = not trapped. (Anstee unpublished data.)

MOUND NUMBER	MICE CAUGHT			
	JULY 1994	SEPT 1994	JULY 1995	SEPT 1995
MB 02	6	2	3	5
MB 03	12	12	11	7
MB 20	4	7	0	1
MB 14	0	2	nt	nt
MB 19	5	0	nt	nt
M 10	nt	nt	1	0
M 12	nt	nt	1	0
M 13	nt	nt	5	0
M 14	nt	nt	0	2
M 20	nt	nt	8	1

reproductive status are lacking for those months. Lactating females and juvenile mice have been recorded in February and March, suggesting pregnancies occur in January. Similarly, lactating females and juveniles in May suggest pregnancies occur in April.

Some data on pregnancy frequency and age-at-onset were obtained from four Ngadji recaptured while monitoring experimental translocations at Jimblebar.

- An adult female, pregnant on 18 September 1995, gave birth to 4 young. It was in early pregnancy when recaptured in mid December 1995 (Ecologia 1996d).
- An adult female, pregnant on 9 September 1995, was again pregnant on 10 November 1995 (Ecologia 1996d).
- A juvenile female (8.4 g; adults weigh about 12 g (range 10–15 g) - Start and Kitchener 1995), caught on 11 September 1995, was pregnant on 9 December 1995 (Ecologia 1996d).
- A juvenile female (weight not recorded) on 12 December 1995 was considered adult, but was not pregnant on 25 February 1996. It was pregnant on 2 May 1996 (Ecologia 1996f).

Although the data are scant, they suggest that *P. chapmani* commonly produces up to four young per litter; like other *Pseudomys* species they have four nipples. Females are capable of breeding soon after maturing and they are capable of producing litters at approximately two to three month intervals.

TABLE 5. Summary of the reproductive records for female *P. chapmani*. Figures in parentheses under 'Lactating' = number of young in litters. Numbers in superscript identify references.[1] A.N. Start (unpublished), [2] Anstee 1994, [3] Dunlop and Pound 1981, [4] Dunlop and Sawle 1980, [5] Ecologia 1996b, [6] Ecologia 1996c, [7] Ecologia 1996d, [8] Ecologia 1996f, [9] Ecologia 1996i, [10] Piggott 1992a, [11] Piggott 1994a, [12] Piggott 1994c [13] Halpern Glick Maunsell (HGM) 1997b, [14] HGM 1997d, [15] HGM 1997e, [16] HGM 1997f, [17] HGM 1998a, [18] HGM 1998b, [19] HGM 1998c.

MONTH	PREGNANT	LACTATING	JUVENILE
January			
February	P [1, 5]	L (4) [5]	J [5]
March	P [5]	L (2) [5]	J [5]
April			
May	P [1, 3, 8, 10,]	L (4) [1,] (4) [3]	J [1, 3, 4, 8, 10]
June	P [12, 14, 16]		J [1, 9, 14]
July	P [2, 14, 16]	L [2, 14]	J [16]
August	P [11, 13]	L [13]	J [11, 13]
September	P [6, 7]	L (1) [1,] (4) [7, 6]	J [2, 6]
October	P [7]		
November	P [11, 12, 13, 15]	L [13]	J [11]
December	P [7, 13, 18, 19]	L [13, 17]	J [7, 13, 17]

TABLE 6. Changes in the estimated density (numbers of mice per hectare) of Ngadji populations at Yarrie and at Marillana Creek (Yandi) (derived from data presented by Halpern Glick Maunsel 1998a and 1998c.). Note that there had been a relatively good season prior to winter 1997 and that vegetation at the Yarri plots was burnt in a wildfire about 5 weeks prior to the summer 1997/8 trapping session.

	WINTER 1996	SUMMER 1996/97	WINTER 1997	SUMMER 1997/98
Yarri	3.4	4.0	8.2	12.1
Marillana Creek (Yandi)	2.0	1.7	3.4	1.9

POPULATION DYNAMICS

The 'boom or bust' life strategy is common among Australian conilurine rodents of the arid zone. Predavec (1994) and Dickman *et al.* (1999) have reviewed the available data. Fluctuations in density of many arid Australian rodent populations are often (but not always) correlated with rainfall patterns. During times of low productivity, rodents are present in very low numbers and some species may be restricted to more favourable refuges.

Like other small rodents of Australian deserts, population density of *P. chapmani* probably fluctuates by several orders of magnitude in response to resource availability, which is influenced by erratic rainfall patterns. The species is obviously capable of persisting in a very inhospitable environment through prolonged periods of drought and it apparently has the ability to increase rapidly in good times. However, there are few reliable data.

The period during which the Ecologia study took place at Jimblebar was one of sustained good rainfall. Although the sample size is too small to test statistically, trap success rates increased three-fold in six months (Ecologia 1996f). Other data have been obtained at Yarrie and Marillana Creek (Yandi) (Table 6; Halpern Glick Maunsel 1998a, 1998c). The trends at both locations were similar except at Yarri in Summer 1997/98 when there was a substantial increase in the number of mice caught despite a reduction in the level of mound activity in the area and little rain after winter 1997. This apparent anomaly at Yarrie may be explained by wildfire that burnt most of the vegetation about five weeks prior to the trapping session. If the fire had reduced food availability, the attractiveness of bait may have been enhanced.

Ngadji may be able to spread from refugia in good times; one was trapped on a mulga flat at least 2 km from the nearest known mound, during a good season (A.N. Start unpublished data). The very similar *P. hermannsburgensis* has been recorded moving 14 km in a straight line in less than two weeks, and several other small mammals of the Australian arid zone have been recorded moving several kilometres (Dickman *et al.* 1995).

Reliance on mounds, which are energetically expensive to construct and are occupied by many generations, could impose a severe constraint on the 'boom or bust' strategy for Ngadji. However, there appear to be two methods by which they can overcome the problem. Firstly, in times of resource abundance, expanding populations can presumably occupy and breed in the surplus mounds which had no resident mice but were used intermittently by residents of other mounds. Indeed the intermittent use of surplus mounds while a population is at low ebb would ensure they remain habitable in readiness for expanding numbers when good seasons arrive. Secondly, increasing the number of mice inhabiting the available mounds probably accommodates a substantial proportion of an increasing population. This may explain variation in the number of home-mound occupants from one to twenty-five animals while there is still a lack of new pebble-mounds.

Implications for Monitoring Ngadji Populations and Assessing their Conservation Status

Besides the increased trap success rates recorded by Ecologia (1996f) and the data obtained at Yarrie and Marillana Creek (Yandi) by Halpern Glick Maunsel (1998a, c; summarized in Table 6), there are no quantitative data on population fluctuations for *P. chapmani*. Other monitoring programs at Marandoo, Yarrie and Marillana Creek (Yandi) are based on mound activity. They detect local extinction and identify population fluctuations accommodated by abandoning or re-occupying mounds. This may account for the change in rate of occupation sometimes reported (e.g. Chapman 1995). Monitoring mound activity will not necessarily detect population fluctuations that are accommodated by the strategies we suggest. However, long-term trapping grids established at Yarri and Marillana Creek (Yandi) since June 1996 may yield some quantitative data (Mark Endersby, unpublished data).

Consideration of the conservation status of Ngadji, like other small arid-zone rodents, should take natural fluctuations in population size into account. Normal fluctuations associated with climatic variables would make it very difficult to use population size to ascertain changes in their long-term conservation status except where they are demonstrated to fail to respond to good seasons. Local extinction is then likely to be evident. These factors have implications for the applicability to Australia's arid zone rodents of some of the criteria established by the IUCN Species Survival Commission (1994) to assess the conservation status of animals. Many of the criteria depend on change to population numbers over substantial time frames. For example:

> 'A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium term future, as defined by any of the following criteria (A to E).
>
> A. Population reduction in the form of either of the following:
>
> 1. An observed, estimated, inferred or suspected reduction of at least 20 per cent over the last 10 years or three generations, which ever is longer, based on (and specifying) any of the following: [direct observation, etc]
> 2. A reduction of at least 20 per cent, projected or suspected to be met within the next 10 years or three generations, which ever is the longer, based on (and specifying) any of the following:' [direct observation, etc].

Identical criteria apply to the Critically Endangered and Endangered categories except that the population reductions are 80 per cent and 50 per cent respectively. Criteria B and C also provide for use of population reduction, but in conjunction with other factors.

Population is defined as 'the total number of mature individuals of the taxon – expressed as numbers of mature individuals only' (IUCN Species Survival Commission, 1994; definitions p. 11).

Thus, these criteria are biologically inappropriate to many Australian arid zone rodents, including Ngadji, which regularly and naturally experience substantial population fluctuations in response to environmental conditions. In conservation terms, significant declines in breeding potential of these species would be caused by local extinctions contracting the Area of Occupancy. For this reason Start (1996) interpreted 'population reduction' in terms of discrete populations in his review of the Ngadji's conservation status. We concur with that approach and consider that his conclusions and recommendations were sound.

ACKNOWLEDGEMENTS

Numerous people and organisations have made this work possible. Ron Hillis of BHP Iron ore Pty Ltd enthusiastically fostered much of the work and co-ordinated the iron ore mining industry's input to the review. Ron Hubery and Jim Stoddart of Hamersley Iron Pty Ltd have fostered a lot of work, particularly surveys conducted by Mark Piggott and studies by Stuart Anstee. This has extended our knowledge of the distribution and biology of *P. chapmani* substantially.

Nick Dunlop and Charles Newland of the Western Australian Department of Minerals and Energy generously gave us their data on location of pebble mounds. Stephen Davies and Kevin Coate provided information on habitats containing pebble mounds in the Gascoyne and Murchison. Steve van Dyck shared his experiences of pebble-mound mice in Queensland and provided a copy of his report to the Australian Nature Conservation Agency (now Environment Australia). Mark Piggott of BHP and Roy Teale of Halpern Glick Maunsell both freely discussed their experiences.

Many Officers from the Western Australian Department of Conservation and Land Management (CALM) have helped us. Norm McKenzie, Peter Kendrick, Keith Morris and Andrew Burbidge provided valuable advice on the review on which this work is based. Steve van Leeuwen, Phil Fuller and Bob Bromilow have given ANS assistance and companionship in the field and Stuart Hay 'drove' the GIS package that prepared the maps.

CALM allowed ANS to devote time to the task. BHP and Hamersley Iron have funded much of the fieldwork by consultant biologists as well as their own staff and BHP funded the costs of the review.

Finally, Norm McKenzie and Andrew Burbidge made valuable comments on drafts of this paper and two referees, Keith Morris and Peter Copley, suggested significant improvements. We value their help.

REFERENCES

Anon. (1979). *Western Australia 1829–1979: An atlas of human endeavour*. Government Printer, Perth, WA.

Anon. (1998). *Western Pebble-mound Mouse* Pseudomys chapmani: *Summary of monitoring and research projects at BHP iron ore Pilbara mining operations*. BHP, Perth, WA.

Anstee, S.D. (1994). *A study of the movement patterns and social structure of the Pebble Mound Mouse* (Pseudomys chapmani). Thesis submitted to the University of Western Australia for a Batchelor of Science Honours Degree.

Anstee S.D. (1995). *Summary of the translocation of* Pseudomys chapmani *from Marandoo to Tom Price.* Unpublished report to the Department of Conservation and Land Management, Perth, WA.

Anstee, S.D. (1996). The use of external mound structure as an indicator of the presence of the Pebble Mound Mouse (*Pseudomys chapmani*) in mound systems. *Wildlife Research* **23**, 429–434.

Anstee, S.D. and Needham, D.J. (1997). The use of a new field anaesthesia technique to allow the correct fitting of radio collars on the Pebble Mound Mouse (*Pseudomys chapmani*). *Australian Mammalogy* **20**, 99–101.

Anstee, S.D., Roberts, J.D. and O'Shea, J.E. (1997a). Social structure and patterns of movement of the Western Pebble-mound Mouse, *Pseudomys chapmani* at Marandoo, Western Australia. *Wildlife Research* **24**, 295–305.

Anstee, S.D., Start, A.N. and Morris, K.D. (1997b). Mound builders of the Pilbara. *Landscope* **12**(3), 42–48.

ANZECC (1991). *List of endangered vertebrate fauna*. Australian National Parks and Wildlife Service, Canberra.

Baynes, A. and Bradshaw, E. (1996). The mammal fauna from an archaeological excavation in Clarke's Cave, coastal north-western Australia. In: Australian Mammal Society's conference handbook: 42nd scientific meeting and *Symposium on the biology and conservation of rodents in Australia*. 8–12 July 1996. P. 23.

Baynes, A. and Jones, B. (1993). The mammals of Cape Range Peninsula, North Western Australia. *Records of the Western Australian Museum, Supplement* **45**, 207–225

Beard, J. S. (1975). *Vegetation survey of Western Australia, 1 : 100 000 Vegetation Series. Sheet 5 Pilbara. Map and Explanatory Notes*. University of Western Australia Press, Perth, WA.

BHP Iron Ore Pty Ltd (1995). *Translocation of Pebble-mound Mice* (Pseudomys chapmani) *from the Jimblebar Mine Site Western Australia*. Translocation proposal submitted to the Director of Nature Conversation, Western Australia. BHP Iron Ore Pty Ltd, Perth, WA.

BHP Iron Ore Pty Ltd (1996). *Orebody 18: Consultative environmental review*. BHP Iron Ore Pty Ltd, Perth, WA.

BHP Iron Ore and Ecologia (1996). *Marillana Creek (Yandi) Expansion: Western Pebble-mound Mouse* Pseudomys chapmani *Management Program*. Unpublished Report. BHP Iron Ore, Perth, WA.

Blakers, M., Davies, S.J.J.F. and Reilly, P.N. (1984). *The atlas of Australian birds*. Melbourne University Press.

Blanford, D.C. and Associates Pty Ltd (1990). *Brockman No. 2 Detrital Project. Consultative Environmental Review*. Hamersley Iron Pty Ltd, Perth, WA.

Braithwaite, R.W., Morton, S.R., Burbidge, A.A. and Calaby, J.H. (1995). *Australian names for Australian rodents*. Australian Nature Conservation Agency, Canberra.

Breed, W.G. (1995). Sandy Inland Mouse *Pseudomys hermannsburgensis*. In: *The Mammals of Australia* pp. 604–605, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

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

Burbidge, A.A., 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.

Butler, W.H. and Butler, M.A. (1983). *Burrup Peninsula fauna survey for Woodside Offshore Petroleum Pty Ltd*. Unpublished report to Woodside Offshore Petroleum Pty Ltd. W.H. & M.A Butler Conservation Consultants, Perth, WA.

Chapman, M. (1995). *Activity status of the Pebble-mound Mouse on the Yarrie Plateau*. Unpublished report to BHP Iron Ore (Goldsworthy) Pty Ltd, Perth, WA.

Coate, K.H. (1995). Exploring the Gardiner and Dennison Ranges. *The Naturalist News* (Newsletter of the Western Australian Naturalists Club) August 1995, 1–2.

Coate, K.H. (1997). Pebble mound mice in the Gascoyne Region of Western Australia. *The Naturalist News* (Newsletter of the Western Australian Naturalists Club) November 1997, 3–4.

Cole, J. (1996). Rodents of the arid Northern Territory. *Conference Handbook: 42nd Scientific meeting and Symposium on the biology and conservation of rodents in Australia* P. 58. Australian Mammal Society.

Cooper, N.K. (1993). Identification of *Pseudomys chapmani*, *P. hermannsburgensis*, *P. delicatulus* and *Mus domesticus* using footpad patterns. *The Western Australian Naturalist* **19**(2), 69–73.

Copley, P. (1988). *The stick-nest rats of Australia.* National Parks and Wildlife Service, South Australian Department of Environment and Planning, Adelaide.

Courtenay, J. (1994). *Report on a preliminary home range and mound usage study of the Pebble-mound Mouse,* Pseudomys chapmani *in Karijini National Park.* Unpublished report to the Western Australian Department of Conservation and Land Management, Perth.

Dames and Moore Pty Ltd (1992). *Goldsworthy Extension Project Phase II; Consultative Environmental Review.* BHP-Utah Iron Ore (Goldsworthy) Ltd, Perth, WA.

Davies, S.J.J.F. (1970). A list of plants and animals found at Mileura, Western Australia Lat. 26°22'S, Long. 117°20'E. *CSIRO Division of Wildlife Research Memorandum* **3**, 1–25.

Davies, S.J.J.F. (1986). A biology of the desert fringe. Presidential address – 1984. *Journal of the Royal Society of Western Australia* **68**(2), 37–50.

Dickman, C.R., Predavec, M. and Downey, F.J. (1995). Long-range movements of small mammals in arid Australia: Implications for land management. *Journal of Arid Environments* **31**, 441–452.

Dickman, C.R., Mahone, P.S., Masters, P. and Gibson, D.F. (1999). Long-term dynamics of rodent populations in arid Australia: The influence of rainfall. *Wildlife Research* **26**(4), 389–403.

Dunlop, J. N. (1995). Pilbara Ningaui *Ningaui timealeyi* Archer, 1975. In: *The Mammals of Australia* pp. 118–119, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

Dunlop, J. N. and Sawle, M. (1980). The small mammals of the eastern Pilbara and the Hamersley Range National Park. In: A fauna survey of the Hamersley Range National Park, Western Australia 1980 pp. 26–30, Muir, B.G. (ed.). *National Parks Authority of Western Australia Bulletin* 1.

Dunlop, J. N. and Pound, I. (1981). Observations on the Pebble-mound Mouse *Pseudomys chapmani* Kitchener, 1980. *Records of the Western Australian Museum* **9**(1), 1–5.

Ecologia (1992). *Nanutarra - Wittenoom Road M29; Tom Price North Project. Biological Survey Report.* Unpublished Report to the Western Australian Main Roads Department. Ecologia Environmental Consultants, Perth.

Ecologia (1995a). *Ore Body 25: Biological Assessment Survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1995b). *Ore Body 18: Biological Assessment Survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1995c). *Yandi Stage II Iron Ore Project. Biological Assessment Survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996a). *Jimblebar Iron Ore Project: Pebble-mound Mouse* Pseudomys chapmani *site survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996b). *Yandi Expansion: Western Pebble-mound Mouse* Pseudomys chapmani *removal program.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996c). *Jimblebar Pebble-mound Mouse* Pseudomys chapmani *Translocation Programme Phase I.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996d). *Jimblebar Pebble-mound Mouse* Pseudomys chapmani *Translocation Programme Phase II.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996e). *Jimblebar Pebble-mound Mouse* Pseudomys chapmani *Translocation Programme Phase III.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996f). *Jimblebar Pebble-mound Mouse* Pseudomys chapmani *Translocation Programme Phase IV.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996g). *Jimblebar Iron Ore Project. Pebble-mound Mouse* Pseudomys chapmani *site survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996h). *Yandi Stage II Iron Ore Project. Pebble-mound Mouse* Pseudomys chapmani *site survey.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Ecologia (1996i). *Yandi II Western Pebble-mound Mouse* Pseudomys chapmani *Winter 1996 monitoring programme.* Unpublished report to BHP Iron Ore Pty Ltd. Ecologia Environmental Consultants, Perth, WA.

Endersby, M. (1994). *Jimblebar Mine Site Biological Survey.* Unpublished report. BHP Iron Ore Pty Ltd, Perth, WA.

Endersby, M. (1997a). *Translocation of the Western Pebble-mound Mouse* Pseudomys chapmani *from the Orebody 18 Mine Site.* Unpublished translocation proposal to the Department of Conservation and Land Management. BHP Iron Ore Pty Ltd, Perth, WA.

Endersby, M. (1997b). Ore Body 18. Western Pebble-mound Mouse Management Programme. Unpublished report. BHP Iron Ore Pty Ltd, Newman, WA.

ESRI (1994). *ARCVIEW Version 2.1.* Environmental Systems Research Institute, California.

Ferguson, K. (1996). *Pebble-mound Mouse assessment at Yarrie.* BHP Iron Ore (Goldsworthy) Pty Ltd, Perth, WA.

Halpern Glick Maunsel (1997a). *Yarri. Western Pebble-mound Mouse* Pseudomys chapmani *1996 management programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997b). *Yarri. Western Pebble-mound Mouse* Pseudomys chapmani *1996 research programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997c). *Yarri.* Pseudomys chapmani *winter 1997 monitoring programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997d). *Yarri. Western Pebble-mound Mouse* Pseudomys chapmani *research programme: Winter 1997.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997e). *Yandi Stage II. Western Pebble-mound Mouse* Pseudomys chapmani *monitoring programme. Summer 1996 monitoring phase.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997f). *Marillana Creek stage II (Yandi Stage II) Western Pebble-mound Mouse* Pseudomys chapmani *monitoring and research programme. Winter 1997 monitoring phase.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997g). *Jimblebar Pebble-mound Mouse* Pseudomys chapmani *translocation programme. Phase V.* Unpublished report on project no. E4351 to BHP Iron Ore Pty Ltd. Halpern, Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1997h). *Jimblebar: Western Pebble-mound Mouse* Pseudomys chapmani *translocation programme. Program review.* Unpublished report on project no. E4351 to BHP Iron Ore Pty Ltd. Halpern Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1998a). *Marillana Creek Stage II (Yandi II) Western Pebble-mound Mouse* Pseudomys chapmani *monitoring programme. Summer 1997 monitoring phase.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1998b). *Ore Body 18* Pseudomys chapmani *translocation programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern Glick Maunsell, Perth, WA.

Halpern Glick Maunsel (1998c). *Yarrie* Pseudomys chapmani *summer 1997 research programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern Glick Maunsel, Perth, WA.

Halpern Glick Maunsel (1998d). *Yarrie* Pseudomys chapmani *summer 1997 monitoring programme.* Unpublished report to BHP Iron Ore Pty Ltd. Halpern Glick Maunsel, Perth, WA.

Hamersley Iron (1992). *Marandoo Project Mining Proposals. Appendix 7: Environmental Management Program.* Hamersley Iron Pty Ltd, Perth, WA.

Hamersley Iron (1994). *Marandoo Project Annual Environmental Report. 1993–1994.* Hamersley Iron Pty Ltd, Perth, WA.

Hamersley Iron (1995). *Yandicoojina Iron Ore Mine and Railway Project: Consultative Environmental Review.* Hamersley Iron Pty Ltd, Perth, WA.

Hobbs, R.J. and Hopkins, A.J.M. (1990). From Frontier to Fragments: European Impact on Australia's Vegetation. *Proceedings of the Ecological Society of Australia* **16**, 93–114.

How, R.A., Dell, J and Cooper N.K. (1991). Vertebrate Fauna. In: Ecological Survey of Abydos-Woodstock Reserve, Western Australia. *Records of the Western Australia Museum* Supplement No. **37**, 78–125.

IUCN Species Survival Commission (1988). *IUCN Red List of Threatened Animals.* IUCN, Gland, Switzerland.

IUCN Species Survival Commission (1994). *IUCN Red List Categories.* IUCN, Gland, Switzerland.

Kerle, J.A. (1995). Central Pebble-mound Mouse *Pseudomys johnsoni.* In: *The Mammals of Australia* pp. 607–608, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

King, D. (1990). The distribution of European rabbits (*Orycytolagus cuniculus*) in Western Australia. *Western Australian Naturalist* **18**(3), 71–74.

King, D. and Smith, L.A. (1985). The distribution of European Red Fox (*Vulpes vulpes*) in Western Australia. *Records of the Western Australian Museum.* **12**(2), 197–205.

Kinnear, J. E., Onus, M.L. and Sumner, N.R. (1998). Fox control and rock-wallaby population dynamics – II. An update. *Wildlife Research* **25**(1), 81–88.

Kitchener, D.J. (1980). A New Species of *Pseudomys* (Rodentia: Muridae) from Western Australia. *Records of the Western Australian Museum* **8**(3), 405–414.

Kitchener, D.J. (1983). Pebble-mound Mouse *Pseudomys chapmani.* In: *Complete book of Australian mammals* pp. 416–417, Strahan, R. (ed). Angus and Robertson, Sydney.

Kitchener, D.J. (1995). Kimberley Mouse *Pseudomys laborifex.* In: *The Mammals of Australia* pp. 608–609, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

Kitchener, D.J. (1985). Description of a new species of *Pseudomys* (Rodentia: Muridae) from the Northern Territory. *Records of the Western Australian Museum* **12**(2), 207–221.

Kitchener, D.J., Adams, M. and Baverstock, P. (1984). Redescription of *Pseudomys bolami* Troughton, 1922 (Rodentia: Muridae). *Australian Mammalogy* **7**(3/4), 149–159.

Kitchener, D.J. and Humphreys, W.F. (1986). Description of a new species of *Pseudomys* (Rodentia: Muridae) from the Kimberley Region, Western Australia. *Records of the Western Australian Museum* **12**(4), 419–434.

Kitchener, D.J. and Humphreys, W.F. (1987). Description of a new subspecies of *Pseudomys* (Rodentia: Muridae) from the Northern Territory. *Records of the Western Australian Museum* **13**(2), 285–295.

Lee, A.K. (1995). *Action Plan for Australian Rodents.* Australian Nature Conservation Agency, Canberra.

Long, J. L. (1988). *Introduced Birds and Mammals in Western Australia.* Agricultural Protection Board of Western Australia. Technical Series **1.** 2nd Edn.

Lorimer, W.J. (1991). *Marandoo Project Area – Land Units.* Unpublished report to Enviroscan, Perth, WA.

Mabbutt, J.A. (1963). General Report on the Lands of the Wiluna-Meekatharra Area, Western Australia, 1958. *CSIRO Land Research Series* **7,** 107–122 + 5 maps.

Main Roads WA (1995). *Marandoo to Great Northern Highway: East West Link Road Across Karijini National Park: Consultative Environmental Review.* Ashburton Shire Council, Tom Price, Western Australia.

Martin, G.R., Twigg, L.E. and Robinson, D.J. (1996). Comparison of the diet of feral cats from rural and pastoral Western Australia. *Wildlife Research* **23**, 475–484.

Maunsell and Partners (1988). *The Vertebrate Fauna of the Proposed Yandicoogina Rail Spur Line.* Unpublished report to BHP – Utah, Perth, WA.

Muir Environmental (1995). *Extensions to Exmouth Water Supply Borefield. Consultative Environmental Review.* Water Authority of Western Australia, Perth.

Ninox Wildlife Consulting (1985). *A Vertebrate Fauna Survey of the Mount Channar Area, near Paraburdoo, Western Australia.* Ninox Wildlife Consulting, Perth, WA.

Ninox Wildlife Consulting (1986). *A second seasonal survey of the Channar Area and a synthesis of all vertebrate data.* Unpublished Report to Hamersley Iron Pty Ltd. Ninox Wildlife Consulting, Perth, WA.

O'Brien, B.J. and Associates (1992). *Marandoo Iron Ore Mine and Central Pilbara Railway: Environmental Review and Management Program.* Hamersley Iron Pty Ltd, Perth, WA.

O'Brien Planning Consultants (1994). *Burrup Peninsula land use and management plan: Technical Appendices.* Unpublished report to The Burrup Peninsula Management Advisory Board. O'Brien Planning Consultants, Perth, WA.

Piggott, M.S. (1991a). *The Pebble-mound Mouse at Marandoo.* Unpublished report to Hamersley Iron Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1992a). *The Range and Distribution of the Pebble-mound Mouse: Interim Report No.1. Marandoo Field Study.* Enviroscan Technical Note **16-04-02/2.** Unpublished Report to Hamersley Iron Pty Ltd. Enviroscan Perth, WA.

Piggott, M.S. (1992b). *The Range and Distribution of the Pebble-mound Mouse: Interim Report No.2. Gregory Range and Rudall River National Park, October 1992.* Enviroscan Technical Note **16-04–02/3.** Unpublished Report to Hamersley Iron Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1992c). *The Range and Distribution of the Pebble-mound Mouse: Interim Report No.3.* Enviroscan Technical Note **16-04–02/4.** Unpublished Report to Hamersley Iron Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1992d). *The Local Distribution of Pebble-mound Mice on the Marandoo Project area.* Unpublished Report to Hamersley Iron Pty Ltd, Enviroscan, Perth.

Piggott, M.S. (1993a). *Yarrie Project Pebble Mouse Management Plan.* Unpublished plan prepared for BHP Iron Ore Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1993b). *An assessment of the local distribution of Pebble-mound Mice (*Pseudomys chapmani*) at Yarrie.* Enviroscan Technical Note **18-02–02/1.** Unpublished Report to BHP-Utah Iron Ore Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1994a). *The Pebble-mound Mice (Pseudomys chapmani) at Yarrie and Area C.* Enviroscan Technical Note 18-02–03/2. Unpublished Report to BHP Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1994b). *The Yarrie Project: Pebble-mound Mouse Monitoring Program, 1993–94.* Enviroscan Technical Note 18-02-06. Unpublished Report to BHP Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1994c). *Yarrie Project: Pebble-mound Mouse Monitoring.* Enviroscan Technical Note **18-03-04/3.** Unpublished Report to BHP Pty Ltd. Enviroscan, Perth, WA.

Piggott, M.S. (1994d). *Range and Distribution of the Pebble-mound Mouse - West Pilbara.* (an Abridged Version of Enviroscan Technical Note **16-04-02/6**). Unpublished report to the Western Australian Department of Conservation and Land Management, Enviroscan, Perth.

Piggott, M.S. (1994e). Conservation management of rare fauna in a new mine development. *Proceedings of the 19th Annual Environmental Workshop* **1,** 263–279.

Predavec, M. (1994). Population Dynamics and Environmental Changes During Natural Irruptions of Australian Rodents. *Wildlife Research* **21,** 569–582.

Predavec, M. (1997). Variable energy demands in *Pseudomys hermannsburgensis*: Possible ecological consequences. *Australian Journal of Zoology* **45**, 85–94.

Randell B.R. (1988). Revision of the Cassiinae. 1. *Senna* Sect. Chamaefistula. *Journal of the Adelaide Botanic Gardens* **12,**19–49.

Ride, W.D.L. (1964). The Mammals of Depuch Island.In: Depuch Island. *Western Australian Museum Special Publication* **No. 2,** 75–78.

Ride, W.D.L. (1970). *A Guide to the Native Mammals of Australia.* Oxford University Press, Melbourne.

Smith, A.P. and Quin, D.G. (1996). Patterns and causes of extinction and decline in Australian Conilurine Rodents. *Biological Conservation* **77**, 1–25.

Spencer, W.B. (1896). *Mammalia*. In: *Report on the Work of the Horn Scientific Expedition to central Australia. Part 2 Zoology*. Spencer, W.B. (ed.). 1–52. Melville, Mullen and Slade.

Start, A.N. (1986). Status and management of Mulga in the Pilbara region of Western Australia. In: *The Mulga Lands*. Sattler, P.S., (ed.). Royal Society of Queensland. Brisbane.

Start, A.N. (1996). *A review of the conservation status of the Ngadji (Western Pebble-mound Mouse)* Pseudomys chapmani *Kitchener, 1980 (Rodentia Muridae)*. Unpublished Report. Department of Conservation and Land Management, Western Australia.

Start, A.N. and Kitchener, D.J. (1995). Western Pebble-Mound Mouse *Pseudomys chapmani* Kitchener, 1980. In: *The Mammals of Australia* pp. 590–592, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

Start, A.N., van Leeuwen, S., Fuller, P. and Bromilow B. (1991). Fire and Mulga. *Landscope* **6**(4), 20–23.

Sutherland, E.F. and Dickman, C.R. (1999). Mechanisms of recovery after fire by rodents in the Australian environment. *Wildlife Research* **26**(4), 405–419.

Thackway, R. and Cresswell, I.D. (1995). *An interim biogeographic regionalisation for Australia: A framework for establishing the National system of reserves, Version 4.0*. Australian Nature Conservation Agency, Canberra.

Thomas, M.O. and Dollman, G. (1909). On Mammals from Inkerman, North Queensland, Presented to the National Museum by Sir William Ingram, Bt., and the Hon. John Forrest. *Proceedings of the Zoological Society of London*, 1908, 788–794.

van Dyck, S. (1996). *Pseudomys patrius*: A reassessment of its identity and status. In *Conference Handbook: 42nd Scientific meeting* and *Symposium on the biology and conservation of rodents in Australia* P.77. Australian Mammal Society.

van Dyck, S and Birch, J. (1996). *Pebble-mound Mice,* Pseudomys patrius *and* Pseudomys sp.*, (Rodentia: Muridae), in Queensland*. Final Report to the Australian Nature Conservation Agency, Çanberra.

van Etten, E.J.B. (1987). *Environmental factors affecting the boundary between Mulga (*Acacia aneura*) and Hummock Grassland (*Triodia *spp.) Communities*. Thesis submitted to Curtin University of Technology for the Degree of Master in Applied Science (Natural Resources).

van Leeuwen, S.J., Start, A.N., Bromilow, R.N. and Fuller, P.J. (1995). Fire and the floristics of mulga woodlands in the Hamersley Ranges, Western Australia. In: *Ecological Research and Management in the Mulgalands* - Conference Proceedings. Page, M.J. and Beutel, T.S. (eds) pp.169–175. University of Queensland Gattion College, Brisbane.

Watts, C.H.S. and Aslin, H.J. (1981). *The Rodents of Australia*. Angus and Robertson Publishers, Melbourne.

Wilson, G., Dexter, N., O'Brien, P. and Bomford, M. (1992). *Pest Animals in Australia: A Survey of Introduced Wild Mammals*. Kangaroo Press, Kenthurst, NSW.

Woinarski, J.C.Z. (1992). Habitat relationships for two poorly known mammal species *Pseudomys calabyi* and *Sminthopsis* sp. from the wet-dry tropics of the Northern Territory. *Australian Mammalogy* **15**, 47–54.

Woinarski, J.C.Z., Braithwaite, R.W. and Maguire, M. (1995). Kakadu Pebble-mound Mouse *Pseudomys calabyi*. In *The Mammals of Australia* pp. 608–609, Strahan R. (ed.). Reed Books, Chatswood, New South Wales.

APPENDIX 1. Location data for *Pseudomys chapmani.* Latitude and longitude are expressed as decimal degrees. Source details are available from the corresponding author.

LOCATION	LAT	LONG	SPECIMEN	ACTIVE MOUNDS	OLD MOUNDS
Abydos, near 28 Mile Camp	21.33	118.88	n	y	y
Barlee Range Nature Reserve	23.13	116.00	y	y	y
Barlee Range RN, south end	23.38	115.92	n	n	y
Barlee Range RN, south end	23.30	115.93	n	n	y
Barlee Range NR, west side	23.17	115.83	n	y	y
Barlee Range NR, north end	23.00	115.83	n	n	y
Boundary Ridge	23.03	118.72	y	y	y
Broadhurst Range, north-west of	22.12	121.93	n	y	y
Brockman Mine	22.30	117.83	n	y	y
Burrup Peninsula	20.58	116.83	n	n	y
Burrup Peninsula	20.58	116.83	n	n	y
Callawa Plateau	20.58	120.87	n	n	y
Cane River Station	22.05	115.62	n	n	y
Channar	23.30	117.73	y	y	y
Chichester Range	21.35	117.23	y	y	y
Cobra Station	24.20	116.47	n	n	y
Collier Range	24.78	119.12	y	y	y
Cookes Hill	20.75	118.68	n	y	y
Croydon	21.12	117.80	n	n	y
Deepdale	21.72	116.18	n	n	y
Dinner Hill	22.62	118.28	y	y	y
Edmund Station	23.77	116.10	n	n	y
Erong Springs Station	25.57	116.67	n	n	y
Fortescue Bridge, south of	21.40	116.05	n	y	y
Fortescue Falls	22.50	118.57	n	y	y
Galteemore Mining Centre	21.85	120.45	n	y	y
Giles Point	23.27	119.17	n	y	y
Gregory Range	22.22	121.30	y	y	y
Gregory Range	22.17	121.40	y	y	y
Jimblebar – Mt Wheelarra	23.38	120.13	y	y	y
Joffre Falls	22.35	118.28	y	y	y
Judal (Mt Hale), near Mileura	26.12	117.50	n	n	y
Karijini NP, Ranger HQ	22.58	118.45	y	y	y
Karratha	20.73	116.87	n	n	y
Karratha	20.73	116.87	n	n	y
Kennedy Range, east of	24.63	115.18	n	n	y
Kenneth Range, Mt Vernon	24.23	118.25	n	n	y
Marandoo	22.62	118.12	n	y	y
Marandoo	22.62	118.01	y	y	y
Marandoo	22.67	118.18	y	y	y
Marandoo	22.62	118.10	y	y	y
Marble Bar	21.17	119.75	n	n	y
McCamey's Monster	23.38	120.00	y	y	y
McKay Range	23.03	122.73	y	y	y
McKay Range	23.00	122.50	n	y	y
McPhee Mining Centre	21.05	118.97	n	y	y
Miles Hill	22.43	122.23	n	n	y
Mileura Station	26.37	117.33	n	n	y
Mindi Spring	22.80	118.32	y	y	y
Mt Anketel	20.67	117.04	n	n	y
Mt Barricade	22.82	118.20	n	y	y
Mt Bilroth	21.62	117.60	n	y	y
Mt Brockman	22.47	117.30	n	y	y
Mt Bruce	22.62	118.05	y	y	y
Mt Bruce	22.62	118.13	n	y	y
Mt Channar	23.33	118.00	n	y	y
Mt Edgar	21.30	120.07	y	y	y
Mt Hanwright	22.32	118.28	n	y	y
Mt Herbert	21.32	117.22	n	y	y
Mt Howieson	22.65	118.25	n	y	y
Mt Howieson, south-east of	22.72	118.33	n	y	y

Mt Leake, near	25.83	119.08	n	n	y
Mt Maguire	23.35	117.82	y	y	y
Mt Meharry	22.98	118.58	n	y	y
Mt Newdegate, near	21.13	121.03	n	n	y
Mt Newman	23.27	119.57	n	y	y
Mt Trevarthon	23.00	118.25	n	y	y
Mt Vigors	22.50	118.23	n	y	y
Mt Webber, Fibre Queen Mine	21.62	119.13	n	y	y
Mt Whaleback – Newman	23.33	119.73	y	y	y
Mt Windell	22.62	118.60	y	y	y
Mulgul Station	24.83	118.47	n	n	y
Munjina Gorge	22.43	118.70	n	y	y
Munjina Gorge, south of	22.52	118.68	n	y	y
Newman, Ore Body 25	23.37	119.73	n	y	y
Nimingarra Hill	20.50	119.90	n	y	y
North Pole, north of	20.92	119.25	n	y	y
North Pole, south of	21.17	119.33	n	y	y
Oakover River	21.37	121.03	n	y	y
Packsaddle	22.97	118.73	y	y	y
Pannawonica, Mesa J,	21.72	116.25	n	n	y
Pardoo Quarry	20.23	119.57	n	n	y
Parry Range	22.42	115.57	n	y	y
Pincunah Hill, south-east of	21.23	118.92	n	y	y
Rhodes Ridge	23.12	119.42	n	y	y
Rio Tinto Gorge	22.41	117.83	y	y	y
Ripon Hills	21.32	121.03	n	y	y
Rooney Creek	22.53	122.30	y	y	y
Rooney Creek	22.48	122.30	y	y	y
Savory Creek	23.88	120.50	n	y	y
Shay Gap	20.50	120.17	n	n	y
Shovelanna Hill	23.33	120.02	y	y	y
Split Rock	21.53	119.58	n	y	y
Strelly Gorge	21.13	119.03	n	y	y
Table Top Hill	22.40	121.95	n	n	y
Tambourah	21.75	119.08	n	y	y
between Tambourah/Woodstock	21.42	119.05	n	y	y
The Governor	23.07	118.85	n	y	y
The Governor, south of	23.08	118.87	y	y	y
The Governor, south of	23.10	118.85	y	y	y
Turee Creek h/s, 35 km ne	23.37	118.45	n	y	y
Weeli Wolli Creek	22.88	119.23	n	y	y
West Angelas	23.18	118.78	y	y	y
West Angelas	23.21	118.82	y	y	y
Whim Creek	20.83	117.83	n	n	y
White QuartzHill	20.68	120.37	n	n	y
White Springs	21.78	118.80	y	y	y
White Springs	21.78	118.80	n	y	y
Woodstock	21.61	118.95	y	y	y
Woodstock	21.58	119.08	y	y	y
Woodstock	21.68	119.05	y	y	y
Woodie Woodie Mine	21.63	121.23	n	y	y
Yandicoogina	22.78	119.22	y	y	y
Yarrie Plateau	20.37	120.20	y	y	y
Zebra Hill, north of	21.12	116.83	n	n	y