

HABITAT USE, DISTRIBUTION AND CONSERVATION STATUS OF THE NABARLEK, *PETROGALE CONCINNA*, AND SYMPATRIC ROCK-DWELLING MAMMALS, IN THE NORTHERN TERRITORY.

SUE CHURCHILL

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A survey of the distribution of the Nabarlek (*Petrogale concinna*) in the Top End of the Northern Territory found the species to be trap shy, secretive and often difficult to distinguish from sympatric *Petrogale brachyotis* in the field. The small number of records for the species is probably attributable to these characteristics. Habitat preferences appeared to be broad with the species utilising a range of rocky environments from the steep and rugged cliffs of the Arnhem Land escarpment to the low granite boulder hills of the Mary River region. The presence of *P. concinna* was correlated primarily with the availability of steep slopes and the presence of a large number of caves. The presence of *P. concinna* was examined in relation to the presence and abundance of 18 species of sympatric mammals. During the study *P. concinna* was recorded from 8 localities, and although further work is required, the species conservation status appears to be secure.

Key words: *Petrogale concinna*, Nabarlek, distribution, habitat, conservation status, rock-dwelling mammals, Northern Territory, *Petrogale brachyotis*, *Macropus bernardus*, *Psuedocheirus dahli*, *Dasyurus hallucatus*, *Parantechinus bilarni*, *Zygomys argurus*, *Z. mainii*.

Sue Churchill, Wildlife Research Unit, Parks and Wildlife Commission of the Northern Territory, PO Box 496, Palmerston, Northern Territory, Australia 0831. Manuscript received 17 February, 1995.

THE Nabarlek, *Petrogale concinna* Gould 1842, is a diminutive rock-wallaby found on the escarpments and rocky hills of the Top End of the Northern Territory and the Kimberley region of Western Australia. The status of *P. concinna* has been under discussion for several years. The species was originally described in 1842 by Gould from a specimen collected in 1839 from the lower reaches of the Victoria River in the Northern Territory (Eldridge 1997). Over the intervening 150 years small numbers of specimens have been collected intermittently over a wide area of north-western Australia.

From 1894 to 1923 specimens were collected at several Northern Territory localities including Daly River, Mary River (Collett 1897), King River, Millingimbi (Thomas 1926), Brocks Creek (Johnson 1964), Oenpelli (Northern Territory Museum), and in Western Australia (Drysdale River, Napier Broome Bay (Kitchener and Vicker 1981)). In the late 1960s and early 1970s, there was another period of collecting activity with specimens from Deaf Adder Gorge, Mt Borradaile, Cooper Creek, Nourlangie Rock, (Calaby 1973, Sanson, Nelson and Fell 1985, Northern Territory Museum) and Augustus Is, Borda Is, and Prince Regent River (McKenzie, Chapman

and Youngson 1975, McKenzie, Burbidge, Chapman and Youngson 1978). There have been few records since, despite 14 major mammal surveys conducted in the region (Woinarski, Braithwaite, Menkhorst, Griffin, Fisher and Preece 1992)

In the Northern Territory, the species was described as 'probably rare' by Sanson (1983), 'probably rare to indeterminate' by Press (1988) and 'potentially vulnerable' by Kennedy (1992). Surveys conducted by Sanson and Nelson in 1976 and 1977 (Sanson et al 1985) failed to locate *P. concinna* during searches in the Pine Creek region, near Mt. Gardiner, Tabletop Range, or in the hills in the upper reaches of the Mary River, all areas previously known to support populations. Similarly, in Kakadu National Park, local aboriginal people regarded it as formerly common in areas where it is now rare or non-existent (Press 1988). In western Arnhem Land *P. concinna* was found by Sanson and Nelson at only one locality, Mount Borradaile (Sanson et al 1985).

This paper presents results of a distributional survey of *P. concinna* and sympatric rock-dwelling mammals in the Northern Territory. The habitat preferences of *P. concinna* were assessed using an analysis in which the vegetation and environmental

features at sites where this species occurs are compared with those where it does not occur. The conservation status of this species is assessed.

METHODS

Distribution records of *P. concinna* from Museum accessions and the literature were used to identify survey areas. Sixteen areas were chosen (Fig. 1), based on these records, reported sightings or the presence of apparently suitable habitat. One to three transects were sampled at each area with a total of 50 transects surveyed. A further eight areas were searched on foot for signs of rock wallabies. This allowed a less detailed examination of large areas of potential habitat in a short period of time, often in areas of difficult access.

Each transect was 250 m long and was trapped for small mammals and macropods for three consecutive days. Traps (total = 50 per site) were placed in two parallel lines 20 m apart, usually with one line running along the base of a cliff and the other line along the rocky scree slope, depending on the geography of the site. Along each line Elliott traps (type A, 9 x 10 x 30 cm) were set 10 m apart and baited with peanut butter and rolled oats. Four wire cage traps were placed on ledges or within boulder piles along each transect within 10 m of the Elliott trap lines. Cage traps were baited with a variety of food stuffs including peanut butter, rolled oats, raisins, apples, potatoes, carrots, figs and nuts. All traps were set and baited before dusk and checked and closed at dawn.

For one evening per transect, during the survey period, a passive watch for macropods was made by sitting quietly in the dark for 2-3 hours at a suitable lookout point, listening and watching for movement. When movement was detected a spotlight was used momentarily to identify the animal. On other nights, active spotlight surveys were conducted by walking along each transect for approximately 30 minutes every night. Mammals seen along the transect at dawn while the traps were being checked or at dusk as the traps were baited were included in the results.

All mammals caught in the Elliott and cage traps were weighed, sexed and examined for reproductive condition. They were temporarily marked on the tail and feet with black felt pen to allow recording of recaptures during the three day trapping session (Churchill 1996).

During the day, searches were made along the transect for the presence of mammal dung. The size and shape of faecal pellets are distinctive for each species. The amount of faecal material observed for each species was recorded as none; traces (only a few

pellets); moderate amount (faecal pellets found in several places along the transect); or large amount (faecal pellets found in large quantities in many places along the transect).

Habitat variables were recorded for every transect from the area between the two lines of Elliott traps and 10 m to either side (250 m by 40 m). The habitat information recorded included latitude, longitude, altitude, distance to nearest permanent water, rock type, aspect (8 cardinal points), % of transect covered with boulders (>30 cm diameter), % of transect with moderate slope (9-20°), steep slope (21-45°) or severe slope (>45°), the maximum, minimum and average height of cliffs along the transect, cliff type (5 categories from sheer cliff to very broken), number of ledges on the cliff (none, 1-5, 6-10, 11-30, >30), and the number of rock crevices (> 15 cm that would provide potential cover for *P. concinna*). The rock crevices were further divided into horizontal splits, vertical splits, overhang caves, solution caves and boulder caves.

Vegetation information was collected from the area between the two lines of Elliott traps (250 m by 20 m). Variables included forest type, the percent cover of projected foliage (in categories: 0-2%, 3-10%, 11-30%, 31-70% and >70%) and average height estimations of major life forms including trees >8 m, trees <8 m, regenerating trees, shrubs >2 m, shrubs <2 m, palms, cycads, hummock grasses, tussock grasses, sedges, forbs and ferns. The relative cover of the five dominant species (highest percentage cover of projected foliage) from each of the upper, middle and lower strata along each transect was listed.

STATISTICAL ANALYSIS

The abundance of *P. concinna* recorded at each transect was related separately to every environmental (habitat and vegetation) variable using Spearman Rank Correlation. For each variable and plant species, transects with *P. concinna* present were compared with those with *P. concinna* absent, using Mann-Whitney tests. As a caveat regarding this procedure, it should be noted that given the number of environmental variables (43) and plant species (92) considered, chance alone would produce many relationships deemed significant at a 5% level.

Partly to circumvent the number of spurious relationships due to examining so many variables univariately, multivariate analysis to the environmental data was also used. To consider the relationships between mammal species abundance and environmental variation ordination of all transects by Hybrid Multi-Dimensional Scaling (HMDS) (Faith, Minchin and Belbin 1987) using 37 of the 43 environmental variables (excluding latitude,

longitude, altitude, aspect, rock type, distance to water) each standardised to range from 0 to 1. The abundance of all mammal species was then related to this ordination space with vector fitting, and the significance of any such relationship was examined with Monte-Carlo simulation (following Kantvilas and Minchin 1989).

Transects were classified by floristics (using range-standardised cover scores) using the flexible unpaired group-mean average (UPGMA) technique (with a Bray-Curtis association measure of $\beta = -0.25$) within the program PATN (Belbin 1987). This process was also used to classify transects by environmental variables. The number of groups was arbitrarily defined, in each case by considering the branching pattern of the dendrogram and attempting to ensure that all recognised groups comprised

several samples. Differences in the abundance of mammal species between each of the defined floristic and environmental groups, were tested using Kruskal-Wallis one-way ANOVA. The relationship between the abundance of *P. concinna* and other species of mammals for each transect, was tested using Spearman Rank Correlation. The correlation between the percentage cover of dominant plant species and abundance of *P. concinna* was tested using Spearman Rank Correlation.

The two species of rock-wallabies recorded during the study, *P. concinna* and *P. brachyotis* were compared for differences in habitat selection. Transects containing *P. concinna* only and transects containing *P. brachyotis* only were compared on environmental and floristic data using Mann-Whitney tests.

Fig. 1. Distribution records of *P. concinna* in north western Australia. Δ represent previous records. \bullet represent sites where *P. concinna* were recorded during this survey. \circ represent sites surveyed during this study where no *P. concinna* were recorded.

RESULTS

SURVEY SITES

A total of 50 transects at 19 sites in 16 localities were sampled during the study period from August 1989 to September 1991. Figure 1 shows the distribution of the areas surveyed during this study. During the study no *P. concinna* were caught in cage traps. Although a variety of baits was used during the study (in the 600 cage trap nights), *P. concinna* were seen to investigate the traps, even sit on them, but showed no interest in entering them. Nelson and Goldstone (1986) used nets to capture specimens at Mt Borradaile but due to limited personnel such a technique could not be used during this study. Passive spotlighting and early morning searching proved to be moderately effective for sighting *P. concinna*, whereas active spotlighting produced few results. *Petrogale concinna* were sighted at seven localities (12 transects) and faecal samples were recorded at an eighth locality.

Data were collected for a total of 19 species of mammals (excluding bats) either caught or sighted during the study (Table 1). These included six species of macropod, three dasyurids, one phalangerid, one petaurid, one bandicoot, six murids and one monotreme. Of the small mammals, 317 individuals were trapped during 7,500 Elliott trap nights. *Pseudomys delicatulus* and *Antechinus bellus* were each recorded at only a single locality (on transects 40 and 42 respectively) and are not included in Table 1. Data on relative abundance were collected on eight species of mammals using presence of faecal pellets (Table 2). *Tachyglossus aculeatus* is the only species included in this list that was not also encountered on the transects.

SURVEY SITES WITH PETROGALE CONCINNA (Table 3)

Hayes Creek (Transects 1-3). *Previous records*: none, but a possible sighting by John Nelson in 1988 (pers. comm.). This site is characterised by 50 m high sheer sandstone cliffs with many ledges and vertical splits. Three *P. concinna* were seen at this site, one was flushed from cover on the rock face during the day and the other two were seen with the spotlight at night about 100m from the base of the cliff. These individuals remained hiding in the long grass while being approached, until when only 10m away they ran through a series of low runways in the grass, occasionally emerging to bound across large rocks. Their gait over the rocks was characteristically horizontal with the tail tip arched up high over their backs and the furred tip fluffed out. *Petrogale brachyotis* at the same locality tended to hold their tails almost horizontal and maintain a more upright stance.

Deaf Adder Gorge, Kakadu National Park (Transects 9-11). *Previous records*: specimens collected by the Northern Territory Museum in 1969.

This species is considered to still be in the area by one of the traditional owners, Jessie Alderson (pers. comm.). No *P. concinna* were seen in this locality although a moderate amount of faecal material was found on transect 10. The topography of the site made observation difficult. The scree slopes were covered with large quartzite boulders that were honeycombed with caves and crevices providing ideal hiding areas. Since many of these rocks were loose it was difficult to avoid making noise while spotlighting. On several occasions, rock-wallaby tails were seen disappearing behind boulders but this was not sufficient to allow identifications. The loose boulder scree also reduced the prospect of finding faecal pellets.

Inbarrin Hills, Kakadu National Park (Transects 12-14). *Previous records*: sighting recorded by Woinarski, Gambold, Menkhorst and Braithwaite (1989). One *P. concinna* was seen inside a small cave during the day and a moderate amount of *P. concinna* faecal pellets was recorded at transect 12. No other *P. concinna* were identified while spotlighting although many *P. brachyotis* were recorded. This isolated group of granite hills contained many boulder caves and splits. It is very similar to the Nellie Creek area (30 km to the south west) where *P. concinna* were collected in 1903 by Tunney (Thomas 1904).

Mount Borradaile, Western Arnhem Land (Transects 30-32). *Previous records*: specimens collected by Boulton and Parker in 1968, research site of Sanson et al (1985). This area supports large numbers of *P. concinna*, with 47 animals sighted along the transects. No *P. brachyotis*, or their dung, were recorded along these transects but several were seen on the upper cliff-line. *Petrogale concinna* appeared to prefer the lower slopes below the main sandstone cliffs where there were large numbers of horizontal splits and ledges. Their behaviour at this site was different to that encountered elsewhere. Several *P. concinna* entered the camp during the day and investigated food supplies. They appeared to be active both day and night at Mount Borradaile and were less shy than at other areas. Spotlighting was quite effective at this site as they sat and looked at the light before moving off. *Petrogale concinna* did not move out onto the floodplain to feed as reported by Sanson et al (1985). At the time of this survey (late March 1990) the floodplain was mostly flooded, but there was a considerable quantity of green grass growing in the small soil pockets between the rocks. *Petrogale concinna* fed at these areas throughout the day and night.

Robin Falls, Litchfield National Park (Transects 33-35). *Previous records*: none. A total of ten *P. concinna* were sighted along transects at this

site. They were seen mainly in the early morning, while sunning themselves on rocky ledges, although one female with a large pouch young was seen in a dry creek bed in the late afternoon approximately 150 m from the cliff area. None were sighted while

spotlighting or passive watching from the cliff top at dusk. This site is a small isolated outcrop of sandstone cliff and boulder piles.

Transect	PC	PBR	MRO	MBE	MAG	MAN	PDH	PBV	IMA	DHA	PBI	ZAR	ZMN	MBU	PNA	RCO
1	2	24	-	6	4	-	9	2	-	-	-	-	-	5	-	-
2	1	12	-	-	-	-	-	-	1	2	-	5	-	1	-	-
3	-	-	-	-	-	-	-	-	2	2	-	5	-	-	-	-
4	-	2	-	-	-	-	-	-	-	-	-	24	-	-	-	-
5	-	4	3	-	-	-	-	-	-	-	-	2	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-
7	-	1	-	2	-	-	-	-	-	1	-	3	-	-	-	-
8	-	2	-	4	-	-	1	-	-	-	-	6	-	-	-	-
9	-	6	-	-	-	-	3	-	-	3	-	5	-	-	-	-
10	-	2	-	1	-	-	3	-	-	1	1	-	5	-	-	-
11	-	1	-	-	-	-	-	-	-	-	-	-	2	-	-	-
12	1	9	-	-	-	-	5	-	-	-	-	5	-	-	-	-
13	-	9	-	-	-	-	1	-	-	-	-	2	-	-	-	-
14	-	4	-	-	-	-	3	-	-	-	-	2	-	-	-	-
15	-	-	-	-	-	-	1	-	-	6	-	4	5	-	-	-
16	-	2	-	-	-	-	-	-	-	4	8	1	5	-	-	1
17	-	-	-	-	-	-	1	-	-	9	-	5	1	-	-	-
21	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	-
22	-	-	-	-	-	2	-	-	-	-	-	1	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-
24	-	1	2	-	-	-	-	-	-	-	-	4	-	-	-	-
25	-	-	1	-	-	-	-	-	-	-	-	3	-	-	-	-
26	-	-	1	-	-	-	-	-	-	-	-	2	-	-	1	-
27	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
28	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	1
30	17	-	-	-	-	-	-	-	-	2	2	-	4	-	-	-
31	12	-	-	-	-	-	2	-	-	1	-	-	2	-	-	-
32	18	-	-	-	-	-	-	-	-	4	2	-	3	-	-	-
33	7	2	-	-	-	-	-	-	-	-	2	2	-	-	-	-
34	2	1	-	-	-	-	1	1	-	1	-	2	-	-	-	-
35	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	2	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
37	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	-	-	1	-	-	-	-	-	5	-	-	-	-	-
40	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	1	-	-	6	-	-	1	-	-
42	-	-	-	-	-	2	-	-	-	-	-	19	-	-	-	-
43	-	-	-	-	3	-	-	-	-	-	-	8	-	-	-	-
44	2	-	-	-	1	1	-	-	-	-	-	2	-	-	-	-
45	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-
47	-	-	-	1	3	1	-	-	-	-	-	-	-	-	-	-
48	-	-	-	-	-	-	-	-	-	4	-	34	-	-	-	-
49	-	-	-	-	-	-	-	-	-	3	-	23	-	-	-	-
50	-	-	-	-	-	-	-	-	-	4	-	16	-	-	-	-
Total captured	0	0	0	0	0	0	0	0	3	47	30	196	27	7	3	2

Table 1. Mammals recorded on each survey transect. Species codes: **PCO** = *Petrogale concinna*; **PBR** = *P. brachyotis*; **MRO** = *Macropus robustus*; **MBE** = *M. bernardus*; **MAG** = *M. agilis*; **MAN** = *M. antilopinus*; **PDH** = *Pseudocheirus dahli*; **PBV** = *Petaurus breviceps*; **IMA** = *Isoodon macrourus*; **DHA** = *Dasyurus hallucatus*; **PBI** = *Parantechinus bilarni*; **ZAR** = *Zygomys argurus*; **ZMN** = *Z. maini*; **MBU** = *Melomys burtoni*; **PNA** = *Pseudomys nanus*; **RCO** = *Rattus colletti*. No mammals were recorded on transects 18, 19, 20 and 38.

Site	PCO	PBR	MAG	MBE	MRO	DHA	PDH	TAC	2	1	3	-	-	2	-	3	-
1	1	3	-	-	1	-	3	-	3	1	3	-	-	1	-	3	-

4	-	3	-	-	2	-	3	-
5	-	3	-	-	2	-	3	-
6	-	2	-	-	2	-	3	-
7	-	1	-	3	-	-	1	-
8	-	1	-	3	-	-	2	-
9	-	3	-	3	-	-	3	2
10	2	3	-	3	-	-	3	-
11	-	1	-	3	-	-	2	-
12	2	3	-	-	3	-	3	2
13	-	3	-	-	3	-	2	2
14	-	2	-	-	3	-	2	3
15	-	-	-	-	3	1	2	3
16	-	2	-	-	3	2	3	3
17	-	2	-	-	3	2	2	3
18	-	-	-	-	3	-	-	-
19	-	-	-	-	3	-	-	-
20	-	-	-	-	3	-	-	-
21	-	1	-	-	3	-	-	-
22	-	-	-	-	3	-	-	-
23	-	-	-	-	3	-	-	-
24	-	2	-	-	3	-	-	2
25	-	2	-	-	3	1	-	2
26	-	-	-	-	3	-	-	1
27	-	1	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-
29	-	1	-	-	-	-	-	-
30	3	-	-	-	-	1	1	2
31	3	-	-	-	-	1	1	1
32	3	-	-	-	-	-	-	1
33	3	2	-	-	-	1	-	-
34	2	2	-	-	-	-	-	2
35	1	1	-	-	-	-	-	-
36	2	1	-	-	-	1	2	-
37	2	-	-	-	-	2	-	2
38	1	1	-	-	-	-	1	2
39	-	-	-	2	-	-	3	1
40	-	2	-	2	-	1	1	-
41	-	1	-	2	-	-	2	-
42	-	2	3	-	-	-	2	-
43	2	-	3	-	1	-	2	2
44	2	-	3	-	-	1	2	-
45	-	-	2	1	-	-	2	3
46	-	1	1	-	-	1	2	3
47	-	2	-	-	-	-	2	3
48	-	-	3	-	2	-	-	2
49	-	-	3	-	2	-	-	2
50	-	-	3	-	3	-	-	3

Table 2. Relative amount of faecal material observed along the survey transects for 8 species of mammals. Faecal abundance is scored as 1 = traces, 2 = moderate, 3 = large amount. Species codes: **PCO** = *Petrogale concinna*; **PBR** = *P. brachyotis*; **MAG** = *Macropus agilis*; **MBE** = *M. bernardus*; **MRO** = *M. robustus*; **DHA** = *Dasyurus hallucatus*; **PDH** = *Pseudocheirus dahli*; **TAC** = *Tachyglossus aculeatus*.

Nimbabirr Hill, Western Arnhem Land (Transects 36-38). *Previous records*: the traditional owners of this area considered this species to be common (Joseph Mangiru pers. comm.). Three *P. concinna* were found in the rocky boulder pile at the

base of the sandstone cliff; two while spotlighting and one was flushed while closing traps at dawn. Nimbabirr Hill is an isolated outlier of the Arnhem Land Plateau.

Murwangle Escarpment, Arnhem Land (Transects 42-44). *Previous records*: in July 1990 K. Menkhorst and N. Gambold (pers. comm.) saw a small rock-wallaby, possibly a *P. concinna* in this area. Two *P. concinna* were seen along the base of a low breakaway cliff during this study and *P. concinna* faecal pellets were moderately common at this site. The area appeared unsuitable for *P. concinna* due to the low laterite cliffs (< 5m) and few caves, ledges or boulders. However there were some small boulder caves found which showed signs of being used recently by *P. concinna*.

Jim Jim Falls camp ground, Kakadu National Park (no transects). *Previous records*: Small rock-wallabies seen here by Park Rangers. Several *P. concinna* were seen amongst a group of *P. brachyotis* on a rocky ledge not far from the camp-ground. They were difficult to identify as they seemed to be interacting with the *P. brachyotis* and could easily be mistaken for their young. However their posture and hopping behaviour were quite distinctive. These individuals were not disturbed by humans and allowed a close approach (<10 m).

SURVEY SITES WITH NO PETROGALE CONCINNA RECORDED

Table 3 shows a list of sites surveyed where *P. concinna* were not recorded during this study. At several sites *P. concinna* had been recorded previously including Nellie Creek where six specimens (2 male, 2 female and 2 pouch young) were collected by Tunney in February 1903 (Thomas 1904) and at East Alligator River where several reports of *P. concinna* in the area were received from local aboriginal people and Parker (1973) reported a specimen collected from this area prior to 1922. At Nabarlek Range several reports were obtained of sightings of *P. concinna* at nearby Myra Falls (Keith Martin and Joseph Mangiru pers. comm.) and the surrounding area.

OTHER AREAS SEARCHED

Several other localities were searched for *P. concinna* by walking along cliff lines during the early morning or late afternoon looking for rock-wallabies and faecal pellets. *Petrogale concinna* were found at only one of these sites, at Jim Jim Falls camp ground in Kakadu National Park (discussed previously).

Site	Transect	Latitude, Longitude	Dates
a) <i>P. concinna</i> recorded			

Hayes Creek	1-3	13° 36'S, 131° 27'E	26-29/8/1989
Deaf Adder Gorge, Kakadu NP	*9-11	13° 07'S, 132° 51'E	10-13/9/1989
Inbarrin Hills, Kakadu NP	12-14	13° 21'S, 132° 01'E	9-12/10/1989
Mount Borradaile, Arnhem Land	*30-32	12° 04'S, 132° 54'E	30/3-2/4/1990
Robin Falls, Litchfield N.P.	33-35	13° 25'S, 131° 09'E	24-27/4/1990
Nimbabirr Hill, Arnhem Land	36-38	12° 18'S, 133° 05'E	10-13/5/1990
Murwangie Escarpment	42-44	12° 50'S, 134° 49'E	29/8-1/9/1991
Jim Jim Falls camp, Kakadu NP	none	13° 13'S, 132° 34'E	27/8/1991
b) <i>P. concinna</i> not recorded			
Mt. Douglas, McKinlay River	4-6	13° 13'S, 131° 45'E	29/8-1/9/1989
Koongarra Saddle, Kakadu NP	7-8	12° 51'S, 132° 51'E	2-5/9/1989
Koolpin Gorge, Kakadu NP	15-17	13° 30'S, 132° 35'E	15-18/11/1989
Jasper Gorge,	18-20	16° 03'S, 130° 45'E	25-28/12/1989
Keep River National Park	21-23	15° 52'S, 129° 03'E	28-31/12/1989
Keep River National Park	24-25	15° 51'S, 129° 07'E	1-4/1/1990
Keep River National Park	26	15° 56'S, 129° 04'E	1-4/1/1990
Nellie Creek, Mary River Station	*27-29	13° 42'S, 132° 03'E	7-10/3/1990
East Alligator River, Kakadu NP	*39-41	12° 28'S, 132° 55'E	22-25/8/1991
Nabarlek Range, Arnhem Land	*45- 47	12° 17'S, 133° 15'E	3-6/9/1991
Mount Bundy	48-50	12° 51'S, 131° 36'E	6-9/9/1991

Table 3. List of survey sites a) where *P. concinna* were recorded during this study. b) where *P. concinna* were not recorded during this study. The * in the transect column denotes that *P. concinna* have been recorded from this site previously.

The areas searched included most of the remaining Northern Territory sites where *P. concinna* had been previously recorded, including Barramundi Hills (sighted by Ian Morris pers. comm.) and Little Nourlangie Rock (sighted by Kym Brennan pers. comm.; Press 1988) in Kakadu National Park. At McCallum Creek two specimens were collected in 1955 and 1957 by R. Petherick (pers. comm.) in Litchfield National Park and at Brocks Creek, 27 miles (43 km) south east of Adelaide River, eight specimens were collected by C. Hoy in 1920 (Tate 1948). At Daly River, (100 miles (160 km) from the mouth) K. Dahl collected specimens in 1894 (Collett 1897) and the Victoria River specimen was collected by Lieutenant J.B. Emery of H.M.S. "Beagle" (Type locality), reweighed in Eldridge (1997). All these areas were examined briefly during this study but no *P. concinna* were found.

There is a dubious record of a specimen from Milingimbi, Crocodile Islands in Arnhem Land (Thomas 1926: 630). The Crocodile Islands are flat mud islands with no topographical relief and appear to be unsuitable for rock-wallabies. The specimen is likely to have come from either the Murwangie Escarpment (approx. 60 km to the south) or from a rocky bar on the Cadell River (approx. 20 km to the west).

HABITAT ASSOCIATIONS

There were significant relationships between the presence of *Petrogale concinna* and several environmental variables. Transects with *P. concinna* present had steeper slopes, a larger number of caves (in particular horizontal and boulder caves), a greater

area of broken cliffs, taller shrubs and a higher percentage cover of shrubs and small shrubs (Table 4). However there was no significant correlation between environmental variables and the abundance of *P. concinna*.

Ordination of sample variables and vector fitting showed no discernible relationship between the abundance of any mammal species and environmental variables. Five environmental and five floristic groups were derived from the UPGMA classification. Table 5 lists the most common plant species in each floristic group and Table 6 lists the mean values of environmental variables within each environmental group. Only the environmental variables that were significantly related to the presence of *P. concinna* are listed.

Differences in mammal abundance between the environmental and floristic groups were tested using Kruskal-Wallis one-way ANOVA. Table 7 shows the relationship between floristic groups and

mammal abundance (both numbers and faecal abundance). No significant relationships were found between floristic groups and *P. concinna*. Table 8 shows the relationships of environmental groups and mammal abundance. Significant ($p = 0.044$) variation was found in the abundance of *P. concinna* faecal material in the 5 environmental groups. However all environmental groups, except group 2, contained *P. concinna* faecal samples.

No significant correlations were found between the abundance of *P. concinna* and the percentage cover of dominant plant species.

Environmental variable	Z value
Steep slope	3.22 ***
Horizontal caves	2.48 **
Boulder caves	2.33 *
Number of caves	2.74 **
Cliff type	-1.90 *
Shrub cover	2.03 *
Shrub height	2.03 *
Small Shrub height	2.05 *

Table 4. Relationship between the presence of *P. concinna* and environmental variables showing significant differences in means between transects with and without *P. concinna* using Mann-Whitney test (significance * = 0.05, ** = 0.01, *** = 0.001).

SYMPATRIC MAMMALS

No significant correlations were found between the abundance of *P. concinna* and the abundance of any other species of mammal. Comparisons between transects inhabited by *P. concinna* and those with *P. brachyotis* showed some significant differences. *Petrogale concinna* was found on transects with more horizontal slit caves ($z = 2.52, p < 0.01$), small shrubs >2 m ($z = 2.05, p < 0.05$), more *Eucalyptus tetradonta* ($z = 2.34, p < 0.05$) and *E. confertiflora* ($z = 1.96, p < 0.05$) and fewer *Zyomys argurus* ($z = -2.2, p < 0.05$) than transects inhabited only by *P. brachyotis*. These differences refer only to the variations in sites where the two species were recorded separately (seven transects with *P. concinna*, twelve with *P. brachyotis*). When all the data were used (including the five transects containing both species) there were no significant differences.

Relationships were examined between the species abundance and faecal abundance of several species of rock-dwelling mammals with floristic groups (Table 7) and environmental groups (Table 8). *Petrogale brachyotis* and *Psuedocheirus dahli* showed a significant relationship with floristic group 1 with species abundance and faecal abundance. *Parantechinus bilarni* was significantly related to floristic group 3 on species abundance. *Zyomys argurus* showed a significant relationship with floristic group 1 but was found in all floristic groups. This was also true in the Gulf of Carpentaria (Churchill 1996) where *Z. argurus* were found associated with similar floristic groups with an overlap of (4 out of 8) dominant plant species common to both studies. *Zyomys maini* abundance

Group 1 (5 transects)	<i>Eucalyptus miniata</i>
	<i>Eucalyptus polycarpa</i>
	<i>Pandanus spiralis</i>
	<i>Sorghum sp.</i>
<hr/>	
Group 2 (13 transects)	<i>Buchanania obovata</i>
	<i>Eucalyptus miniata</i>
	<i>Livistona sp.</i>
	<i>Owenia vernicosa</i>
	<i>Planchonia careya</i>
	<i>Plectrachne pungens</i>
<hr/>	
Group 3 (14 transects)	<i>Allosyncarpia ternata</i>
	<i>Erythrophleum chlorostachys</i>
	<i>Ficus virens</i>
	<i>Grewia retusifolia</i>
	<i>Pandanus basedowii</i>
<hr/>	
Group 4 (9 transects)	<i>Canarium australianum</i>
	<i>Owenia vernicosa</i>
	<i>Grewia retusifolia</i>
	<i>Brachychiton paradoxum</i>
	<i>Cochlospermum fraseri</i>
	<i>Eucalyptus confertiflora</i>
	<i>Ficus virens</i>
<i>Livistona humilis</i>	
<hr/>	
Group 5 (9 transects)	<i>Buchanania obovata</i>
	<i>Erythrophleum chlorostachys</i>
	<i>Eucalyptus clavigera</i>
	<i>Eucalyptus phoenicea</i>
	<i>Sorghum sp.</i>
<hr/>	
	<i>Terminalia ferdinandiana</i>

Table 5. List of most common plant species in each floristic group

was significantly related to floristic group 3 and did not occur in groups 1 and 2. Interestingly another large species of rock-rat, *Z. palatalis*, showed a similar floristic relationship in the Gulf of Carpentaria, with a considerable overlap (4 out of 6 species) in dominant plant species composition in the significant floristic groups (Churchill 1996). *Zyomys maini* also showed a significant relationship with environmental groups based on species abundance, utilising sites characterised by large numbers of horizontal caves and very little shrub cover. *Dasyurus hallucatus* did not show a significant trend in species abundance but exhibited a significant relationship to floristic group 3 based of faecal abundance.

Faecal abundance showed significant trends with floristic and environmental groups for several species of macropods: *Macropus agilis* with floristic

Environmental group	1	2	3	4	5
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variable					
Steep slope	76.6	74.0	28.6	68.0	0
Horizontal caves	5.4	10.4	6.6	2.3	1.5
Boulder caves	5.7	4.1	16.4	0.1	10.9
Number of caves	18.0	23.3	32.3	4.0	18.4
Cliff type	2.2	2.4	1.4	2.8	3.2
Shrub cover	1.3	0.2	1.1	0.1	0.9
Shrub height	2.7	0.3	2.7	0.4	2.0
Small Shrub height	1.2	0.4	1.3	0.5	0.13
No. of Transects	15	10	10	7	8

Table 6. Mean values of environmental variables in each of the designated environmental groups. Only environmental variables that were significantly correlated to the presence of *P. concinna* (see Table 4) are listed.

Groups	1	2	3	4	5	F value	p value
a) Species							
<i>P. brachyotis</i>	0.347	0.023	0.015	0.010	0.017	13.43	0.0001
<i>P. dahli</i>	0.259	0.012	0.056	0	0.044	4.290	0.005
<i>P. bilarni</i>	0	0	0.241	0.019	0.025	4.077	0.006
<i>Z. argurus</i>	0.118	0.441	0.023	0.032	0.024	15.04	0.0001
<i>Z. maini</i>	0	0	0.386	0.015	0.040	6.815	0.0002
b) Faeces							
<i>P. brachyotis</i>	2.778	0.556	1.143	0.692	1.000	9.765	0.0001
<i>M. agilis</i>	0	2.000	0.214	0	0	14.0	0.0001
<i>M. antilopinus</i>	0	1.000	0	1.000	0.200	3.204	0.0213
<i>M. robustus</i>	1.889	1.111	0.643	2.077	0	4.387	0.004
<i>P. dahli</i>	2.778	1.333	1.857	0.077	0.400	21.039	0.0001
<i>D. hallucatus</i>	0	0.111	0.643	0.308	0	2.803	0.0368
n	9	9	14	13	5		

Table 7. Comparison of a) mammal numbers and b) faeces abundance for different species, (using Kruskal-Wallis one-way Anova), with floristic groups classified by UPGMA.

Groups	1	2	3	4	5	F value	p value
a) Species							
<i>Z. maini</i>	0.025	0.400	0.280	0	0	5.495	0.001
b) Faeces							
<i>P. concinna</i>	0.250	1.285	1.000	0	0.666	2.660	0.044
<i>M. agilis</i>	0.750	1.714	0	0	0.200	5.688	0.0009
<i>M. antilopinus</i>	0	1.285	0.400	0.900	0.067	2.905	0.032
<i>M. robustus</i>	1.625	1.000	0.900	2.700	0.467	6.337	0.0004
n	8	7	10	10	15		

Table 8. Comparison using Kruskal-Wallis one-way Anova, of a) mammal numbers and b) faeces abundance for different species with environmental groups classified by UPGMA.

group 2; *M. antilopinus* with groups 2 and 4 and *M. robustus* with group 4. *Petrogale concinna*, *M. agilis* and *M. antilopinus* were most abundant in environmental group 2 and *M. robustus* in group 4.

DISCUSSION

Identification of *P. concinna* was sometimes difficult due to their habit of mixing into a group of *P. brachyotis*. *Petrogale brachyotis* are very variable in size and markings and *P. concinna* often looked like young *P. brachyotis*. The small size of *P. concinna*

and their habit of holding the tail high and arched over the back with the end tuft of fur fluffed out when moving were the most obvious distinguishing features.

The shy behaviour of *P. concinna* also presented difficulties for spotlighting. Any noise or movement would cause them to hide within caves or boulder piles. It was usually difficult to walk along a scree slope at night spotlighting without making a considerable amount of noise. Passive watching often

proved to be a more effective method of seeing *P. concinna*.

The large population of *P. concinna* at Mount Borradaile was an exception. This area was surveyed during March, at the end of the wet season, when the area was inundated with water to the edge of the rocky outcrop effectively turning this area into an island for almost half the year. At this time *P. concinna* were easily seen during most of the day and night feeding on the small pockets of fresh sedges and grasses, such as *Cyperus spp.* and *Eriachne spp.*, amongst the rocks. Even at midday they could be seen looking out from caves and ledges.

Sanson et al (1985) found that during the dry season *P. concinna* moved out onto the flood plain to feed on *Marsilea crenata*, a siliceous fern. They found that *Marsilea* contained very high levels of silica (up to 26% dry weight) and they hypothesised that the unusual dentition in *P. concinna* (an apparently unlimited number of supernumerary molars allowing high rates of molar replacement (Sanson 1983)) was related to the highly abrasive diet of *Marsilea* fern. Further work is needed to determine the dry season diet of *P. concinna* at other localities. During this study *Marsilea* was searched for at every site but without success. This implies a more complex dietary story than that proposed by Sanson.

There are several possible reasons for the lack of significant trends in the relationships between environmental variables and abundance of *P. concinna*, such as measuring the wrong environmental or floristic variables, or sampling too few localities and transects. It is also possible that this species is found in such a variety of rocky environments that there are few features common to all these sites.

Sympatric mammal species showed a larger number of significant trends with environmental and floristic variables. The more specialised rock-dwelling species such as *P. brachyotis*, *Psuedocheirus. dahli*, *Parantechinus bilarni* and *Zyomys spp.* were most abundant in floristic groups 1 to 3 whereas the more widespread species *M. robustus* and *M. antilopinus* were found in floristic groups 4 and 5.

One of the most striking aspects of this study was the great diversity of rocky sites occupied by *P. concinna*. The habitat types used ranged from the granite boulder piles of Inbarrin Hills, to the broken cliffs of Mount Borradaile and the high cliffs of Hayes Creek, even including the low laterite breakaways of the Murwangie escarpment. This implies that the species, because of a broad habitat tolerance, may be far more common than the few

records indicate. This conclusion is supported by the recent additions to the number of sites known to support *P. concinna* (this study, Woinarski et al 1992).

The only common feature of these sites was the presence of steep slopes and caves. Short (1982) found that *Petrogale penicillata* in New South Wales occupied sites with three times the number of caves and twice the number of ledges than adjacent unoccupied areas. In this study *P. concinna* abundance showed a positive correlation with the presence of caves but not ledges.

Short also found that *P. penicillata* preferred cliffs that received sun for much of the day, usually those with a northerly aspect. No aspect preferences were found with *P. concinna*. Ambient temperatures at latitudes surveyed during this study are very stable (particularly within caves) and warm throughout the year, caves having an average ambient temperature of 27°C (Churchill 1991), thus providing thermally stable retreats, regardless of aspect.

The difficulty in trapping *P. concinna* and its secretive nature in comparison to the more common *P. brachyotis* may have caused it to be overlooked during surveys in the past. Woinarski et al (1992) summarised the results of 16 regional mammal surveys conducted in north western Australia since 1974. *Petrogale concinna* were recorded in only three of these surveys (Kakadu Stages I and II; Kakadu Stage III and Prince Regent River).

Surprisingly, *P. concinna* were found to be present in areas subject to considerable human disturbance such as Jim Jim camping ground in Kakadu National Park and Robin Falls in Litchfield National Park. These sites are visited daily by tourists during most of the dry season.

THREATS

In southern Australia several species of *Petrogale* are threatened by predation from foxes or from competition and habitat destruction by goats, rabbits and sheep (Johnson, Burbidge and McKenzie 1989, Burbidge and McKenzie 1989). None of these introduced species occur in the Top End of the Northern Territory or the northern Kimberley Region of Western Australia. The rocky habitats and escarpments in these areas are relatively pristine and a large proportion of this environment is within National Parks, Nature Reserves or Aboriginal Land. These areas are unlikely to undergo any major changes in land management in the foreseeable future.

All recently extinct macropods (except *Macropus greyii*) are within the critical weight range of 35 to 4,200 gms adult weight (Burbidge and McKenzie

1989). *Petrogale concinna* with a weight of only 1-1.7 kg (Sanson 1983) falls within this range.

Johnson, Burbidge and McKenzie (1989) examined the reasons for macropod extinctions and found no clear primary causes but found significant correlations with changed fire patterns and invasion by foxes. Recent changes in fire regimes for the sandstone ranges of the wet-dry tropics are thought to be threatening much of its distinctive and relictual fauna (Bowman, Wilson and Fensham 1990, Begg, Martin and Price 1981, Churchill 1996). Some areas are likely to be more susceptible to fire than others. For example the granite boulder hills of the Pine Creek and Mary River area would provide *P. concinna* little protection from fires. Changes in fire frequency and intensity may explain the lack of recent records of *P. concinna* in these areas.

Woinarski et al (1989) have pointed out that these granite boulder hills in the Pine Creek and Mary River area (where many of the early specimens were recorded; e.g. Dahl 1897, Thomas 1904 and Collett 1897) are also subject to substantial gold mine development and mineral exploration. These granite boulder areas are often quite small and are isolated from each other by large areas of open woodland, which offer little cover for movement between isolates.

CONSERVATION STATUS

Although further work is needed to establish the conservation status of *P. concinna*, this survey indicates that the species has not undergone a drastic decline in recent decades and that it is likely to be relatively widespread throughout the rocky hills and escarpments of the Top End.

From the results of this study it is considered that *P. concinna* is more common than previously believed. Difficulties in seeing and accurately identifying this species are likely to be the major factors influencing assessment of its status. Difficulties involved in trapping *P. concinna* have influenced their poor representation in recent museum collections. Earlier methods of obtaining specimens (e.g. shooting) were far more likely to produce results than modern non-destructive trapping techniques and survey programs.

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