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Spatial ecology of the mulgara in arid Australia: impact of fire history on home range size and burrow use

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Abstract

Knowledge about the spatial ecology of small mammals in relation to fire history in arid zones in general and Australia in particular is limited. Here, we report data on the spatial ecology of the brush-tailed mulgara *Dasycercus blythi* in the hummock grasslands of Uluṟu – Kata Tjuṯa National Park during winter 2006, the beginning of the breeding season for this species. About 73% of the study area had been burnt in 2002 and spinifex cover was sparse. Mulgaras *Marsupialia: Dasyuridae* (six males and three females) were implanted with radio-transmitters and monitored daily for between 6 and 55 days. All mulgaras appeared to use defined home ranges, which overlapped extensively with those of several neighbours. Spatial overlap occurred between as well as within sexes. On average, males (25.5 ha) occupied significantly larger home ranges than females (10.8 ha). Mulgaras used a number of burrows within home ranges and several were used by more than one individual. Moreover, occasionally, two individuals used the same burrow simultaneously. Home ranges and burrows encompassed both mature spinifex *Triodia basedowii* and open regrowth areas and mulgaras did not exhibit a significant preference for either habitat type. However, three males were killed by introduced-predators and they all lived predominantly in the open regrowth area. We conclude that mulgaras do not select the dense cover of mature spinifex habitat, and might be subjected to increased risk from introduced predators, especially following fire.

Introduction

The carnivorous marsupials (family Dasyuridae) consist of 69 species in 20 genera that are confined to Australia, Tasmania, New Guinea and adjacent offshore islands (Wilson & Reeder, 2005). Dasyurids range in size from 4 g to 10 kg, occupy a range of environments and are insectivorous/carnivorous (Menkhorst & Knight, 2001). A diversity of species inhabit the arid and semi-arid regions of Australia (Dickman, 2003), where they often dominate native small mammal assemblages (Dickman *et al*., 2001).

Over the past 200 years, in the wake of European settlement, many mammal species including two dasyurids have become extinct in arid and semi-arid mainland Australia (Short & Smith, 1994; Cardillo & Bromham, 2001; Kinnear, Sumner & Onus, 2002). Several potential causes for this decline have been proposed including changes in fire regime and land use (e.g. grazing), the introduction of foreign species especially the European rabbit *Oryctolagus cuniculus*, red fox *Vulpes vulpes* and house cat *Felis cattus* (Short & Smith, 1994; Short & Turner, 1994; Burrows *et al*., 2003) and epizootic diseases (Abbott, 2006). In the face of the high rate of species loss, concern has been expressed about the conservation status of other species of dasyurid marsupials. Foremost among these is the brush-tailed mulgara *Dasycercus blythi*, which occurs in hummock grasslands on sandy soils across extensive parts of South Australia, the Northern Territory and Western Australia (Menkhorst & Knight, 2001). The taxonomy and naming conventions of the mulgara are currently under review. Here, we follow Woolley (2005) in recognizing our study taxon as the brush-tailed mulgara *D. blythi* Waite, 1904. The brush-tailed mulgara has an apparently patchy distribution, a fluctuating population size, which varies with environmental conditions, and a generally low population density (Masters, 1993, 1998; Dickman *et al*., 2001). The patchiness of the distribution and sedentary lifestyle (i.e. stable home range) suggest that this species has specific and possibly limiting habitat requirements that might also restrict dispersal and re-colonization (Masters, 1993, 2003). Furthermore, fire appears to have an impact on population size, with fewer animals being found in the years after a burn (Masters, 1993) and hence the alteration of fire regimes following European settlement and appropriate use of fire management are potentially significant conservation issues.

Understanding the ecology and response to disturbance by species such as the nocturnal brush-tailed mulgara requires intensive, long-term research to obtain difficult to acquire data. In this respect, the population of *D. blythi* at the Yulara bore fields adjacent to Uluṟu – Kata Tjuṯa National Park provides a valuable opportunity because population monitoring has been ongoing for over a decade and previous research provides important baseline data (Masters, 1993, 1998, 2003; Masters, Dickman & Crowther, 2003). A wildfire in October 2002 that burnt most of the habitat used by this population provided an opportunity to carry out a natural experiment to investigate the use of a habitat mosaic consisting of mature (unburnt for 20 years) and recently burnt hummock grassland. We investigated the spatial ecology of nine brush-tailed mulgaras for 73 consecutive days of tracking in the Austral winter of 2006. In particular, we assessed use of burnt and unburnt habitat, home range size, burrow-use patterns and the vulnerability of tagged animals to predation.

Materials and methods

The study was conducted in Uluṟu – Kata Tjuṯa National Park, Northern Territory (25°20′S, 131°02′E), during the Austral winter of 2006. The study area was located on a sand plain interspersed with low dunes situated close to the bore fields that provide the water supply for Yulara, the nearest town. Mature spinifex *Triodia basedowii*, which had not been burnt for 20 years, covered about a third of the area (the average fire cycle is 25 years; Griffin, 1990). The majority of the study area had been burnt in October 2002 and in these parts of the study area, spinifex was still sparse and the low shrub *Rulingia lexophylla* was abundant. Burnt and unburnt areas were mapped by walking the boundary between the two habitat types with a handheld Global Positioning System (GPS; Garmin 12XL, Garmin Ltd., Olathe, KS, USA) set to 'track log'. Data were down-loaded to a PC and then mapped in ArcView GIS 3.2. Weather data were obtained from Yulara and the headquarters of Uluṟu – Kata Tjuṯa NP, *c.* 11 and 13 km from the study site, respectively.

Animals were captured in aluminium box traps (Elliott type A) set every 10–15 m along seven parallel transects spaced 100 m apart with 25 traps per transect. In addition, traps were occasionally set close to burrows used by radio-tagged individuals. Traps were baited with peanut butter mixed with rolled oats and provided with some polyester fibre material for insulation. Traps were checked once in the early morning and remained open throughout the day as reptile activity was low during winter.

Species identification of mulgaras was based on morphology (i.e. tail shape, number of premolars and nipples) and DNA analyses (Adams, Cooper & Armstrong, 2000; Woolley, 2005). Mulgaras were implanted intraperitoneally with radio-transmitters (Sirtrack 2.4–3.9 g, Sirtrack, Havelock, New Zealand). Two different loop antenna configurations were used to account for the differences in size and mass of transmitters. Heavy males received transmitters with a larger loop antenna boosting reception range. In addition, while being anaesthetized, each animal was injected subcutaneously with a identification transponder (PIT) tag (Destron Fearing Corp., Destron Technologies, South St. Paul, MN, USA). Surgery was performed under general oxygen/isoflurane anaesthesia (Körtner & Geiser, 2000). After surgery, mulgaras were held for *c.* 24 h and provided with fresh minced kangaroo *ad libitum*. They were then released the following evening at the point of capture. At the end of the study, animals were re-trapped and the transmitter surgically removed, except for one female carrying pouch young.

We radio-tracked individuals between 10 June and 21 August 2006 and attempted to find the burrows of all implanted individuals daily. Burrows were marked, their physical characteristics were documented and the location was recorded using a handheld GPS. For the four individuals with the longest monitoring periods, night-time locations were also recorded by radio-tracking. To avoid interference with normal activity patterns, night tracking only commenced after sufficient daytime locations had been obtained. Fortunately, when approached at night, animals tended to move only a short distance and hide in dense vegetation or burrows. Again, locations were recorded with a GPS. To minimize serial correlation, the time interval between location records was at least 1 h, and not more than four records per night per individual were obtained. For these four animals, night-time records accounted for an average of 18 ± 4% of all records.

To allow comparison with other studies and because of the limited data we collected for some individuals, home ranges based on trapping and predominantly day-time radio-tracking locations were calculated as 100 and 90% minimal convex polygons (MCP; Animal Movement V2; Hooge & Eichenlaub, 1997). For the latter, 10% of locations were removed as outliers based on the harmonic mean of the individual's dataset. To assess the reliability of the home range estimates, home range size was plotted against the number of location records, using stepwise removal of a random number of records from each individual's dataset. Data were analysed using the 'MCP Sample size Bootstrap' procedure in Animal Movement V2 (Hooge & Eichenlaub, 1997).

Habitat selection (i.e. fire age: burnt vs. unburnt area) was analysed in two steps (Aebischer & Robertson, 1993). In the first step, the composition of the home ranges was compared with the overall composition of the study area defined by a circle large enough to contain all the location records for all animals (255 ha; Fig. 1). In the second step, the relative proportion of all locations and burrow locations for each animal per habitat type was compared with the overall composition of its home range. Before analysis, percentage values were arcsine-transformed.

The degree of overlap between home ranges of two neighbouring individuals was analysed by intersecting the two home-range polygons (100% MCP) and calculating percentage overlap. As this percentage is dependent on home range size and therefore typically differs between the

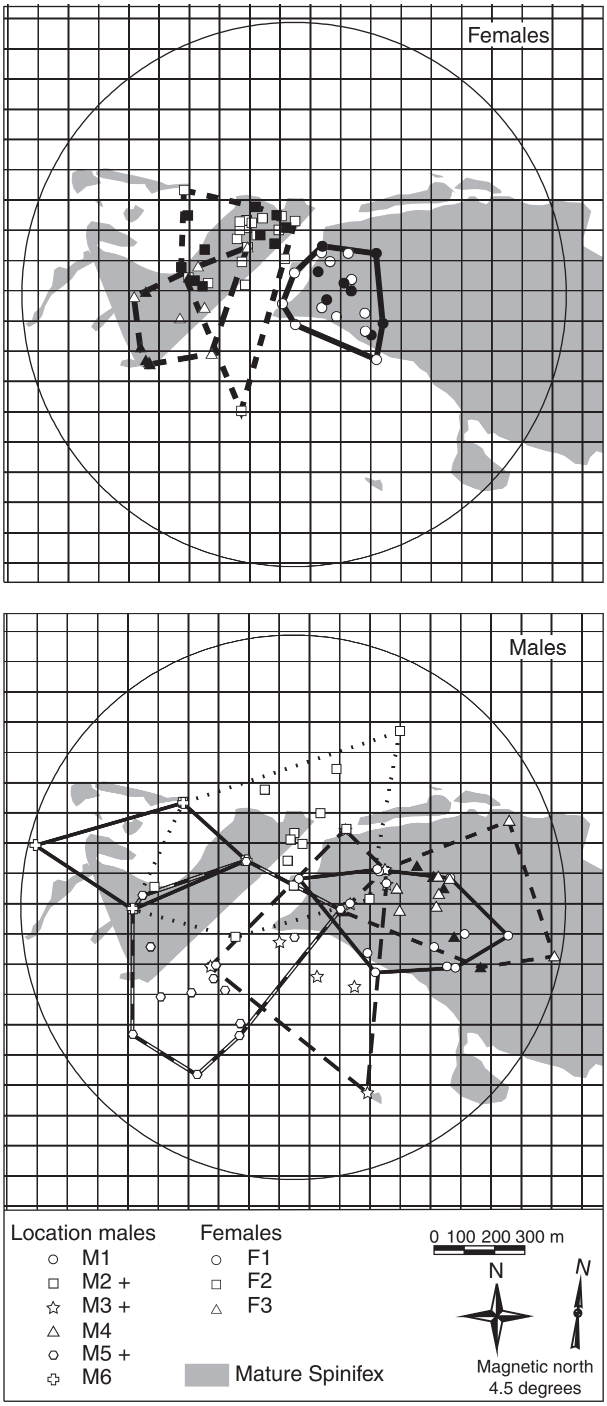

Figure 1 Home range estimates minimal convex polygons (MCP 100%) and all location records for three female (upper panel) and six male (lower panel) mulgaras *Dasycercus blythi*. A number of locations represent multiple records. White symbols refer to daytime burrow locations and black symbols to night-time records. The greyed areas represent unburnt, mature spinifex *Triodia basedowii*. The circle encompasses the 'study area' used as the reference for our habitat analyses. Animals killed by predators are marked (+).

two members of the pair analysed, we used the following index to take into account the home range size of both individuals (Atwood & Weeks, 2003):

$$[(\text{area}_{\alpha\beta}/\text{home range}_{\alpha}) \times (\text{area}_{\alpha\beta}/\text{home range}_{\beta})]^{0.5}$$

where $\text{area}_{\alpha\beta}$ is the overlapping area and home range_{α} and home range_{β} are the home ranges of individuals α and β, respectively. As all home ranges overlapped substantially for a number of animals, only animals with overlapping home ranges were considered as neighbours, that is non-overlapping pairs were excluded from the analysis.

Unless stated otherwise, data are presented as means ± 1 SD. Averages were compared using a *t*-test and '*n*' refers to the number of animals and '*N*' to the number of observations.

Results

Study animals

During the course of the study, 12 (8 M:4 F) individual mulgaras were trapped and of these nine (6 M:3 F) were implanted with transmitters for the radio-tracking study. On average, males (85.0 ± 12.7 g, $n = 8$) were heavier than females (57.4 ± 3.9 g, $n = 4$; $t = 5.62$, $P < 0.001$, d.f. = 9). Individual animals were monitored for varying lengths of time ranging from 6 to 55 days (Table 1). Short monitoring periods were attributed to premature transmitter failure or predation. Animals were tracked for a total of 277 radio-tracking days and on only six occasions was an animal with a functional transmitter not located. Therefore, both types of implantable transmitters were suitable for radio-tracking these medium-sized burrowing mammals. Overall, seven of the nine transmitters deployed were retrieved. When transmitters were removed from two of the females (12 and 19 August) they did not carry pouch young. In contrast, the third female was carrying newly born pouch young (17 August) precluding surgery. One male 'disappeared' and was not re-trapped, meaning that its transmitter probably failed.

Weather

Weather conditions were predominantly fine throughout the study period. However, in excess of 30 mm of rain fell between the 13 and 16 of July. Cloudy conditions and early morning fog persisted for several days afterwards.

Burrows

All mulgaras used multiple burrows and overall 68 burrows were found. Ten of these were used by more than one individual (subsequently by up to five) and hence the sum of burrows on the basis of individuals was 85 (Table 1). The maximum number of burrows used by an individual was 15 (Table 1). About 47% of the burrows were used by an individual only once (Fig. 2a). However, some individuals

Table 1 Body mass and tracking statistics for the nine mulgaras *Dasycercus blythi* monitored

ID	Body mass (g)	Number of days monitored[a]	Total number of locations[b]	Number of burrows[b]
M1	92.6	18	22 (3)	9 (2)
M2	101.7	25	33 (13)	10 (6)
M3	80.9	8	11 (6)	6 (3)
M4	73.4	52	61 (0)	10 (0)
M5	98.0	30	34 (25)	12 (8)
M6	89.6	6	9 (6)	3 (1)
F1	61.9	54	63 (5)	15 (4)
F2	55.8	47	62 (8)	14 (2)
F3	52.8	37	51 (6)	6 (1)

[a] Exclusive of days when animal could not be located.

[b] Numbers in brackets refer to burrows/records situated in the burnt area.

M, males; F, females.

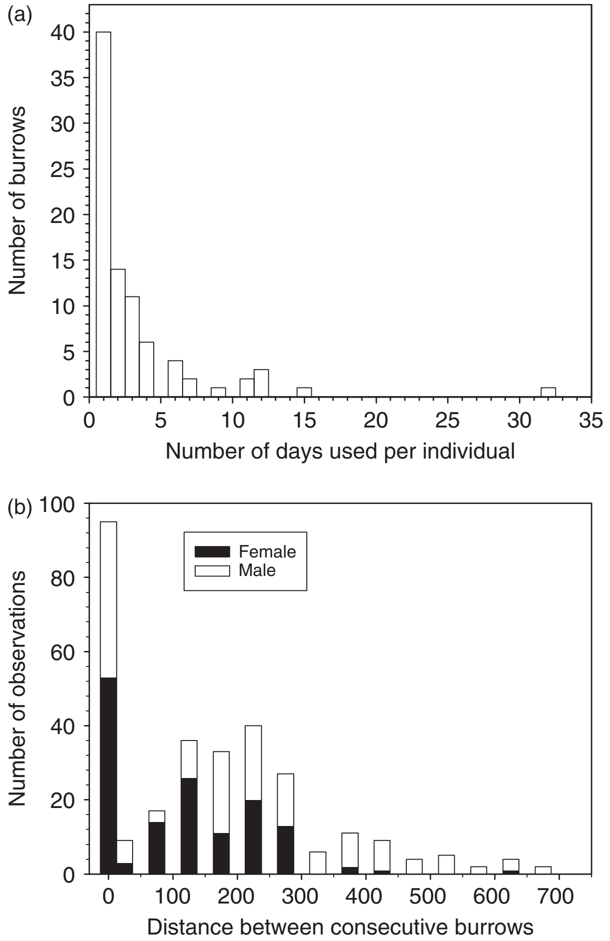

Figure 2 Burrow use by individual mulgaras *Dasycercus blythi* (a). The number of burrows plotted against the number of days a specific burrow was used by an individual over the course of the study. Linear distance (m) between burrows used on consecutive days for female and male mulgaras (b). The zero columns represent reuse of the same burrow.

used the same burrow repeatedly for long periods. One male returned to the same burrow on 32 of the 52 days monitored. Shuttling between two burrows was common and on 95% of all observations ($N = 191$; $n = 9$), <1 week elapsed before a burrow was revisited. When mulgaras changed burrows, the linear distance between burrows used on consecutive days was typically between 100 and 300 m (Fig. 2b). More distant movements were more common by males (Fig. 2b), although the maximum linear distance between two consecutive burrows used was indistinguishable between males (571 ± 100 m, $n = 6$) and females (446 ± 138 m, $n = 3$; $t = 1.39$, $P = 0.26$, d.f. = 3).

The number of burrows used per individual increased over time but there was no indication that a maximum number had been reached even after 55 days, which was the longest monitoring period for any individual. In fact, the data were described reasonably well by a linear regression (#burrows $= 4.25 + 0.17 \times$ #days; $R^2_{\mathrm{adj}} = 0.54$, $P = 0.015$, $n = 9$), indicating little burrow fidelity. On average, burrows were used for only 3.2 ± 1.6 days ($n = 9$) by an individual.

Mulgara burrows varied considerably in complexity and location. Many appeared to have only a single entrance but some had many entrances spread over several square metres. A mound of loose soil in front of an entrance was not uncommon. Burrows were situated in patches with mature spinifex as well as areas that had recently burnt. Entrance holes were often hidden under dense spinifex while others were unconcealed and some distance away from any vegetation. Sixteen burrows were built into the root systems of grevilleas *Grevillea eriostachya*. For the 20 single-entrance burrows for which the aspect could be determined with confidence, the orientation of burrow entrances was randomly distributed ($P = 0.9$, Rayleigh test). In a number of cases, it was clear that other animals, particularly goannas (*Varanus* spp.), great desert skinks *Egernia kintorei* and rabbits, had constructed or modified the burrow system. One burrow was excavated to re-catch one of the study animals. The burrow had two entrances and was only ~24 cm deep with some dried grass lining the nest chamber. During the July rainfall period, all animals used burrows away from standing water but there was no visible blocking of the entrances.

Habitat preference

The 2002 wild fire burnt ~73% of the study area, leaving patches of mature spinifex of various sizes (Fig. 1). Mulgaras used both burnt and unburnt habitat and overall the habitat composition of the animals' home ranges did not differ from that of the whole study area ($n = 8$, $t = 3.12$, $P = 0.11$). However, differences between individual home ranges were pronounced, with one male's home range being situated entirely in mature spinifex, whereas that of another contained only 31% mature spinifex (Fig. 1). Likewise, within each home range, the distribution of burrows matched the availability of the two habitat types ($n = 8$, $t = 0.46$, $P = 0.66$).

Table 2 Home range estimates for mulgaras *Dasycercus blythi* and placement of home ranges in respect to habitat burnt in the 2002 fire

ID	MCP 100% (ha)	% of MCP burnt	% of records in burnt area	MCP 90% (ha)
M1[a]	15.1	1.8	13.6	10.1
M2[b]	36.3	58.8	39.4	22.4
M3[b]	26.6	68.8	54.5	15.8
M4	19.4	0.0	0.0	5.5
M5[b]	30.1	68.9	73.5	25.8
M6[a]	*12.7*	*63.2*	*66.7*	
F1	8.7	24.8	7.9	4.7
F2	15.4	56.2	12.9	6.6
F3	8.3	21.9	11.8	8.3

[a] Premature transmitter failure.

[b] Animals killed by cats or foxes.

Numbers in italics were excluded from analyses, because of small sample sizes.

MCP, minimal convex polygons.

Home range

Home range estimates were primarily based on the location of burrows, but for the four animals tracked day and night we found no indication that burrow sites and activity areas were distinct (see also Masters, 2003). When home range size was plotted against the number of location records, female home range size approached a plateau between 20 and 50 data points. Hence, our estimates likely approximate the real home range size. The plot for one male (M1) approached a plateau after ~10 location records, but for all other males, home range size was still increasing at the end of tracking, even for M4, for whom we obtained 61 records over 52 days. Hence, our estimates of home range size for most males are likely underestimates.

The 100% MCP home range size differed significantly ($t = 3.33$, $P = 0.021$, d.f. = 5) between males (25.5 ± 8.4 ha, $n = 5$) and females (10.8 ± 4.0 ha, $n = 3$; Table 2). This gender difference was not significant when 90% MCPs were compared ($t = 2.4$, $P = 0.07$, d.f. = 4).

The home range (100% MCP) of a mulgara overlapped with on average 5.3 ± 1.4 ($n = 9$) neighbours (range 4–8). No males or females possessed exclusive home ranges or territories. Substantial overlap occurred both between within the sexes. Overlap between neighbours averaged 23.8 ± 17.7% (24 combinations). Only two of the three female home ranges overlapped precluding further analysis. However, overlap between male–male pairs (18.0 ± 15.9%, $N = 11$) was not significantly different from that between male–female pairs (28.8 ± 19.1%, $N = 12$; $t = 1.49$, $P = 0.15$, d.f. = 20).

Home range overlap extended to burrow use. Ten of the 68 burrows that we found were used by two to five individual mulgaras. Although most often different individuals used the same burrow on different days, on 13 occasions pairs of mulgaras shared a burrow. Male–female pairs were observed on six occasions, female–female pairs five times (the same two individuals each time) and a male–male pair twice (the same pair in the same burrow on consecutive days). In addition, targeted trapping around burrows resulted in the capture of up to three individuals at the same site on one night.

Predation

Three radio-tagged males were killed by predators. Identification of the predators involved was possible on all occasions based on tracks and bite marks on transmitters. Two animals were killed and eaten by cats. Transmitters were not ingested and their wax coating contained the impressions of sharp canines. In one case, the cat also left the snout of its prey and the ID transponder. Tracks (cats and mulgara) suggested that both mulgaras had been killed at the site where the transmitter was found. The third mulgara was killed by a fox and the carcass cached in a shallow depression. The carcass remained largely intact and death was caused by crushing the thorax without breaking the skin. Substantial internal tissue bruising demonstrated that the animal had been killed and not scavenged. All three mulgaras killed were males and all had occupied home ranges consisting of > 50% burnt vegetation. Tracks of wild dogs, foxes and cats were seen frequently throughout the study area.

Discussion

The arid zone of Australia is characterized by low and unpredictable rainfall, extreme temperature fluctuations and scarce resources. Particularly in resource-poor sand country, many small mammals must exploit ephemeral food sources by moving often over many kilometres without establishing a stable home range (Morton, 1978; Read, 1984; Dickman, Predavec & Downey, 1995; Letnic, 2002; Haythornthwaite & Dickman, 2006). In contrast, mountain ranges attract more rain and water is also stored more efficiently, providing more stable environmental conditions, which should favour sedentary species (Pavey, Goodship & Geiser, 2003). Therefore, the sedentary life style of the mulgara (Masters, 2003; this study) is unusual for a medium-sized dasyurid inhabiting sandy spinifex habitat. It is possible that the larger body size allows mulgaras to exploit a larger variety of food sources extending to small vertebrates, which can sustain them year round in the same area (Chen, Dickman & Thompson, 1998; Masters, 1998). Nevertheless, the habitat and lifestyle of mulgaras would suggest that they have relatively large home ranges in comparison with species from more productive habitats. The estimates we report are larger than those reported previously for this species (Masters, 2003), although ours are still likely to be underestimates at least for males. The 90% MCP for males (15.9 ± 8.4 ha) was almost twice the size of that recorded previously by day and night radio-tracking for the same location (8.1 ± 4.7 ha), whereas the difference for females was less pronounced: 6.6 ± 1.8 ha versus 4.7 ± 3.7 ha (Masters, 2003). These differences might be attributable to the substantially longer monitoring periods for some individuals in our study and the fact that monitoring included the mating period for mulgaras (Michener, 1969; Masters, 1998), when home ranges appear to be the largest (Masters, 2003). The 2002 wildfire, which burnt part of the study area, might have also reduced resource availability (Masters, 1993; Letnic *et al*., 2004) requiring increased home range size. This assumption is supported by the observation that the two males living mainly in mature spinifex had relatively small home ranges (Table 2).

Interspecific comparisons of home range size among dasyurids are difficult because of the paucity of data. However, for other mammals, home range size is correlated with body mass in an almost linear fashion (Lindstedt, Miller & Buskirk, 1986). Accordingly, the home range size for mulgaras falls between that of the smaller *Pseudantechinus macdonnellensis* (Pavey *et al*., 2003), *Antechinus stuartii* (Lazenby-Cohen & Cockburn, 1991), *Sminthopsis leucopus* (Laidlaw, Hutchings & Newell, 1996) and *Sminthopsis psammophila* (Churchill, 2001) and the larger *Phascogale tapoatafa* (Soderquist, 1995), although these animals occur in a variety of habitats. The fact that mulgaras fit the line does not support our prediction that because of their sedentary life style in an arid environment, they would have a large home range for their body size. Perhaps the apparently patchy distribution of mulgaras (Gibson & Cole, 1992) indicates that this species persists predominantly in better quality environments such as the bore fields where the ground water table is relatively close to the surface (Masters, 1998). Furthermore, the ability to enter daily torpor (Geiser & Masters, 1994) is likely to play an important part in overcoming energetic bottlenecks.

Like many other dasyurids, mulgaras use a number of burrows within their home range, while occasionally favouring one or two burrows for prolonged periods. Shuttling between two burrows and the usual distance of 100–300 m between burrows suggests that it is costly to return to the same burrow after foraging over a large home range. It appeared that mulgaras regularly seek new burrows while abandoning those used previously. This leads them to frequently use burrows of other species. We found no indication that burrows were in short supply and thus a limiting resource. Nevertheless, some of the burrows appeared to be complex as described by Woolley (1990), with multiple entrances indicating prolonged use by several mulgaras, but also other species. Indeed, as is the case with home ranges, burrows did not appear to be defended by an individual. Many burrows were frequented by a number of individuals, burrow sharing was observed occasionally and targeted trapping around some burrows yielded a number of individuals. Although mulgaras were not gregarious in a strict sense, it is likely that mulgaras show not only a high degree of social tolerance but also interact frequently at focal points/burrows, and the scat deposits outside some burrows are likely to function as scent marks (see also Woolley, 1990). These social interactions warrant further research.

Masters (1993) reported reduced abundance of most small mammal species including mulgaras in recently burnt areas when compared with mature spinifex habitat, whereas moderate cover reduction by harvesting had no apparent impact on population size (Masters *et al*., 2003). Our data suggest that such differences in population size, at least for mulgaras, are probably not attributed to a pronounced habitat preference as overall mulgaras used habitat in accordance with availability. However, dense spinifex clearly provides increased protection from predators when active above ground (Haythornthwaite, 2005). Judging from the tracks of introduced predators, these were abundant at the site during the study, possibly due to the number of human settlements in the vicinity. Direct evidence of predation by introduced carnivores on threatened species is generally scarce. It is therefore disturbing that we observed a significant proportion of our study animals being killed by cats and foxes. Although the sample size was too small for any statistical analysis, if the observed mortality rate (three of the nine individuals are killed over ~2.5 months) is indicative of long-term average mortality rates, then the mulgara population mulgara is likely unsustainable. However, all three males were killed during the mating season, had home ranges containing mainly recently burnt habitat and were found away from mature spinifex, all of which may have contributed to the relative high predation rate. Increased mortality might also be implicated in a previous study where recapture events were common in mature spinifex but rare in recently burnt plots (Masters, 1998). Burning is part of the natural succession of spinifex grasslands and has long been used as a management tool. However, inappropriate use of fire could substantially increase predation risk and endanger some populations of native mammals as, for example, has been postulated for the northern quoll (*Dasyurus hallucatus*; Oakwood, 2000). Clearly, further research is needed to address the impact of introduced predators on the population dynamics of mulgaras and the interaction between fire and predation risk. Meanwhile, it appears prudent to implement predator control around known mulgara populations as a precautionary measure particularly in the years following a fire.

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