Do cat restrictions lead to increased species diversity or abundance of small and medium-sized mammals in remnant urban bushland?

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We took advantage of cat regulations enacted within differing subdivisions in the City of Armadale, Western Australia, to test the hypotheses that the species diversity (measured by the Shannon-Weiner index) and abundance of small and medium-sized mammals should be higher in native bushland within or adjacent to subdivisions where cats are restricted compared to similar areas where cats are not restricted. There were three different regimes of cat regulation: no-cat zone (strict prohibition of cat ownership applying in one site), compulsory belling of cats and night curfew at one site, and unregulated zones (free-roaming cats applying at two sites). Both sets of cat regulations were in place for approximately 10 years prior to our survey. We also measured structural and floristic features of the vegetation at each site that might influence the species diversity and abundance of small and medium-sized mammals independently or interactively with cat activity.

No significant differences in species diversity were found across the sites and KTBA (known-to-be-alive) statistics for Brushtail Possums *Trichosurus vulpecula* and Southern Brown Bandicoots *Isoodon obesulus*, the two most abundant medium-sized mammals present, were similar across all sites. The smaller Mardo *Antechinus flavipes*, which could be regarded as the most susceptible to cat predation of all the native species trapped because of its size, was trapped mostly at an unregulated cat site. Total mammals trapped at the unregulated cat sites exceeded those caught at the two sites with restrictions, but these unregulated sites also had significantly denser vegetation and there was a borderline ($p = 0.05$) rank correlation between vegetation density and mammal captures across all sites. It appears that pet cats are not the major influence on the species diversity or abundance of small and medium-sized mammals at these sites and that vegetation characteristics may be more important.

INTRODUCTION

WHILE it is undoubted that pet cats *Felis catus* hunt and kill wildlife (Churcher and Lawton 1987, Barratt 1998, Gillies and Clout 2003, Woods *et al*. 2003, Lepczyk *et al*. 2004), the impact of this predation on prey populations is debated in Australia (contrast Nattrass 1992 and Chaseling 2001 with Paton 1991) and overseas (contrast Fitzgerald 1990, Patronek 1998 with Lepczyk *et al*. 2004 and van Heezik *et al*. 2010). In Australia, proponents of the view that predation by pet cats causes declines in wildlife populations are supported by evidence from declines in the Superb Lyrebird *Menura novaehollandiae* population at Sherbrooke Forest, Victoria (Bradley and Bradley 1990, Dickman 1996) and declines in the Eastern Barred Bandicoot *Perameles gunnii* at Hamilton, Victoria (Seebeck *et al*. 1990, Dufty 1994). The alternative view that such impacts are exaggerated is supported by the persistence of some bird species in suburban Canberra, Australian Capital Territory, despite high predation by pet cats (Barratt 1998) and Grayson *et al*.'s (2007) finding that bird species richness in suburban Perth, Western Australia, is unrelated to pet cat densities.

Given the plausibility of significant impacts but the uncertainty of their extent, a precautionary approach would be to impose some regulations on pet cats until further empirical evidence resolves the extent of any impact (Grayson and Calver 2004). Increasing numbers of local councils across Australia are doing so, with some reporting implementation of measures including confinement of cats to owners' premises at all times (Baker 2001), prohibiting cat ownership in new sub-divisions (Buttriss 2001), night-time curfews (Pergl 1994) and impounding free-roaming cats in declared conservation areas (Moore 2001). If such measures are beneficial for wildlife, one might expect increases in the species diversity or abundance of wildlife in remnant bushland within or adjacent to districts where regulations were enacted relative to neighbouring areas where there are no regulations.

In this study, we took advantage of cat regulations enacted within differing subdivisions in the City of Armadale, Western Australia, to test the hypotheses that the species diversity and abundance of small and medium-sized mammals should be higher in native bushland within or adjacent to subdivisions where cats are restricted compared to similar areas where cats are not restricted. There were three different regimes of cat regulation: no-cat zone (strict prohibition of cat ownership applying in one site, hereafter "no-cat"), compulsory belling of cats and night curfew at one site (hereafter "curfewed cat"), and

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unregulated zones (free-roaming cats applying at two sites, hereafter "unregulated cat"). We predicted that if hunting by pet cats plays a role in species diversity and abundance of small and medium-sized mammals, then:

(i) in terms of mammal species present, the unregulated cat sites should be more similar to each other than to either the no-cat site or the curfewed cat site;

(ii) the species diversity of mammals should be greater at the no-cat and curfewed cat sites than at the unregulated cat sites; and

(iii) the abundance of mammals should be greater at the no-cat and curfewed cat sites than at the unregulated cat sites.

We tested these predictions by systematic trapping between September 2003 and July 2005. We also measured structural and floristic features of the vegetation at each site that might influence the species diversity and abundance of small mammals independently or interactively with cat activity.

METHODS

Study sites

The four study sites were located within the City of Armadale (32°15'S, 116°02'E), approximately 29kms south east of Perth, Western Australia (Figure 1). Small and medium-sized mammals known to occur in the area are listed in Table 1. In the text below we designate sites by both name and a code letter. Throughout the methods we then use the code letter only to reduce dense repetition of site names, but revert to names in results and discussion where they are used less frequently.

Site A (Stinton Cascades, unregulated cat) is a reserve of approximately 133 hectares located on Irymple Road, Karragullen. It is surrounded predominantly by orchards with a low density of houses where no restrictions are imposed on cat ownership or husbandry. It is part of a series of nature reserves connected ultimately to the Darling Range state forest. The site is 302 m above sea level and inclines gently with a slope of 8° in an east-west aspect. The dominant

Fig. 1. (a)

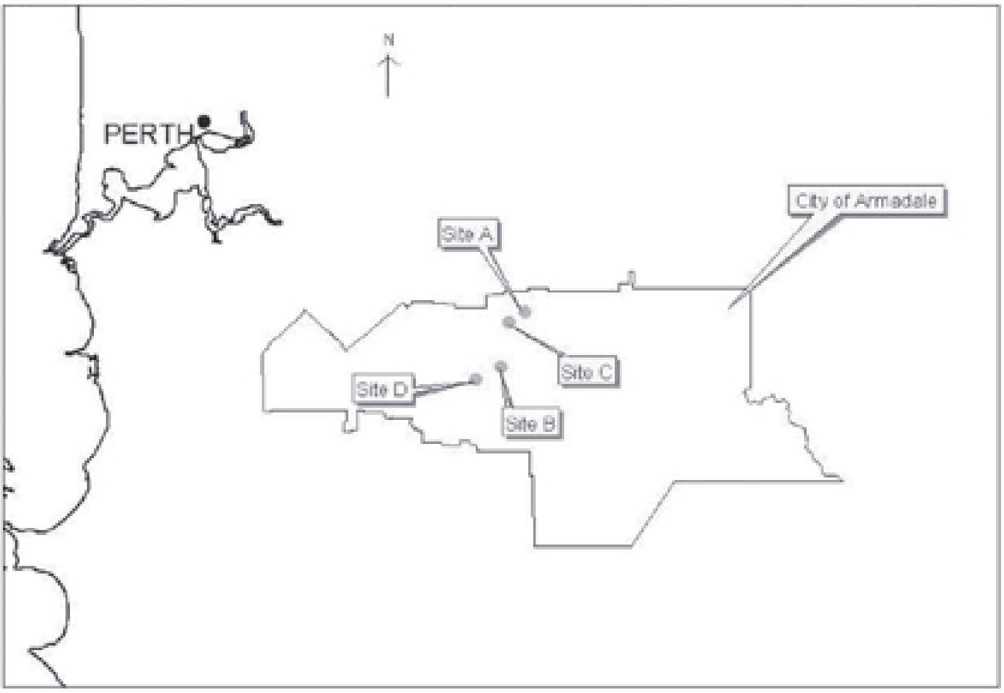

Fig. 1. Location of study sites within the City of Armadale (a) in relation to location of Perth, Western Australia and city boundaries (Scale: 4mm = 1km), and (b) residential subdivisions, showing roads (Scale: 1.3mm = 1km). Darker road lines indicate major roads. Areas of highest denisty of minor roads (too small to show individually) are shaded grey. There were no restrictions on cat ownership in Sites A and C. Cats at Site B were required to wear bells and were confined at night, while cat ownership was prohibited at Site D. Managers of the Araluen Country Club Estate, adjacent to Site B, stipulate that all cats within this estate must wear a collar with two bells, and all cats must be curfewed at night (Araluen Country Club design guidelines and covenants January 1994, page 20). The residents in this estate (developed in 1994) are bound by these guidelines which were set out with the purpose of promoting fauna conservation within the surrounding state forest and reserves.

Fig. 1. (b)

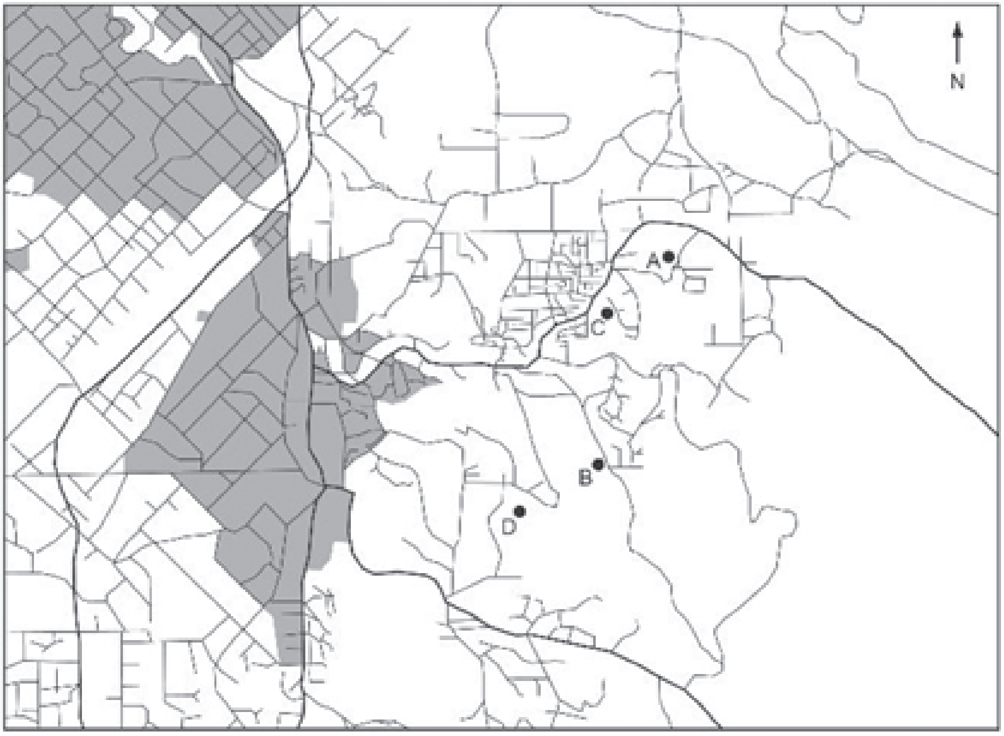

Table 1. Small and medium-sized mammals that are known to occur within the City of Armadale and hence might have been trapped in this study. Names and weights conform to van Dyck and Strahan (2008). Susceptibility to cat predation is based on assessments in Table 2.3 of Lilith (2007).

Name	Mean weight (g)	Susceptibility to cat predation
Native species		
Mardo, *Antechinus flavipes*	55 (m) 34 (f)	H
Brush-tailed Phascogale, *Phascogale tapoatafa*	231 (m) 156 (f)	L
Western Pygmy Possum, *Cercartetus concinnus*	13	L
Brushtail Possum, *Trichosurus vulpecula*	3 270	L
Echidna, *Tachyglossus aculeatus*	2 000–7 000	L
Southern Brown Bandicoot, *Isoodon obesulus*	890 (m) 620 (f)	H
Introduced species		
House Mouse, *Mus musculus*	Up to 25	H
Black Rat, *Rattus rattus*	280	H
Rabbit, *Oryctolagus cuniculus*	1 590 (m) 1 570 (f)	H

overstorey species are Jarrah *Eucalyptus marginata* and Bull Banksia *Banksia grandis*, with occasional patches of Marri *Corymbia calophylla*. Mid and understorey vegetation comprises *Persoonia longifolia,* Grass Trees *Xanthorrhoea preissii* and *X. gracilis*, Zamia *Macrozamia riedlei*, *Patersonia* sp. and Hairy Glandflower *Adenanthos barbigera*. Although this reserve is easily accessible by the public, it has been set aside predominantly for nature conservation and there are few walking tracks.

Site B (Araluen, curfewed cat) is located within Araluen Estate on Heritage Drive, Roleystone. The lower (south-east) part adjoins state forest (over 1800 hectares). The western and south western parts of this site are adjacent to the reserve and water catchment area of the Churchman Brook Reservoir, which forms part of the Perth Metropolitan Integrated Water Supply System. The Araluen Country Golf course and residential housing (350 hectares in total) are located on the east of Heritage Drive. Regulations in force since 1994 stipulate that all cats within this estate must wear a collar with two bells and be curfewed at night (Araluen Country Club design guidelines and covenants January 1994, page 20). The site is gently inclined with a slope of 5° in a north facing aspect (altitude of 297 m). Jarrah and Sheoak *Allocasuarina fraseriana* are the dominant overstorey tree-species with occasional occurrences of Marri trees. Other vegetation includes Bull Banksias, Parrot Bush *Dryandra sessilis*, Grass Trees and Yellow Buttercup *Hibbertia hypericoides*. The site is accessible to the public but has few walking tracks.

Site C (Warwick Savage Park, unregulated cat) is located on Simons Drive, Roleystone. It is surrounded by residential housing on minimum block sizes of 2 hectares, where there are no restrictions on cat ownership or husbandry. It is the steepest of the sites with a 9° slope in an east facing aspect with an altitude of 297 m above sea level. The dominant overstorey species are Jarrah, Marri, and Bull Banksia, with a structurally dense midstorey of Water Bushes *Bossiea aquifolium* and an understorey of grass trees, Zamia and *P. longifolia*. Approximately 4 hectares of the total 11 hectares of this reserve (across a fire break) was burned in October 2002 (M. McIntosh, City of Armadale, pers. comm.), which affected the initial trapping grid for only one trapping season (session 1 — September 2003). The trapping grid was subsequently offset approximately 50 metres to a new location for the trap sessions 2, 3, 4 and 5. This site is accessible to the public and is predominantly reserved for nature conservation.

Site D (Churchman Brook Estate, no cat) is located on a track off Churchman Brook Road adjacent to a new housing development with a minimum lot size of 3 000 square metres, where cat ownership has been prohibited since the first release of land in 1994 (C. Gaskin, City of Armadale, pers. comm). It is close to a water catchment reserve managed by the Water Corporation (of Western Australia) where the trapping grid was located. The total water catchment management site is 1561 ha and public access is prohibited. It is the flattest of all the sites with a slope of 4° in an east facing aspect (altitude of 299 m) and is dominated by Marri and Sheoak in the overstorey and Parrot Bush in the mid-storey layer. The sparse understorey vegetation consists mainly of grass trees.

Trapping schedule and trapping methods

Trapping commenced in September 2003 and followed a schedule that avoided endangering animals by trapping only in cooler months: September 2003 (Sites C and D), March–April 2004 (Sites A and B followed by Sites C and D), June 2004 (Sites A and B followed by Sites C and D), July 2004 (Sites A and B), August–September 2004 (Sites A and B followed by Sites C and D), June 2005 (Sites A and B) and July 2005 (Sites C and D). Each trap session at each site consisted of four consecutive nights of trapping (except for session 5 where there were only three nights), resulting in a total of 19 nights of trapping for each site and a total of 76 for the study. Elliott traps (32cm x 9cm x 9cm) (Elliott Scientific, Upwey, Victoria) were used for small (< 200g) mammal trapping (e.g., Catling and Burt 1994, Catling *et al*. 1997, Wilson *et al*. 2001) and Tomahawk cages (48cm x 21cm x 21cm) were used to capture medium to large (200g–>6kg) ground-dwelling or arboreal mammals (e.g., Laurance 1994).

The trapping methodology followed the protocols of the Western Australian Department of Environment and Conservation (DEC) for the survey of small to medium sized mammals (P. Mawson, DEC, pers. comm). In all cases grids were 20–30m from the boundary of the reserve, well within the 100m pet cats are known to roam into reserves (Kays and DeWan 2004).Twenty-five Elliott traps were set in a grid of five transects, 20 metres apart (total grid size 100m x 100m). One cage trap was placed at the end of alternate lines starting from A, so there was a cage trap at A1 and A5, C1 and C5 and E1 and E5 respectively in each of the trapping grids, giving a total of six cage traps in each site. The number of cage traps was doubled in site C (Warwick Savage Park) in session 4 (August 2004) because there was high disturbance of Elliott traps from either Southern Brown Bandicoots *Isoodon obesulus* or Brushtail Possums *Trichosurus vulpecula*. Therefore the number of cage traps was increased to see if this would catch the offending bandicoots and possums and improve Elliott trap success. The additional six traps were placed on B3, C2, C3, C4, D3 and E3.

Traps were baited with a mixture of rolled oats and peanut butter. They were checked each morning and any animal caught was identified to species, weighed and sexed. New recruits to the trapping survey were marked with individually numbered ear-tags for large mammals or individual ear-notches for small mammals. The animals were then released at the point of capture.

Monitoring of cat presence

To confirm the presence of predators at the four trapping sites, two scent stations were set up at opposite ends of each trapping grid (i.e., two at A1 and E5). Each scent station consisted of an aluminium tray (38 x 90cm) covered with smoothed yellow sand, placed lengthwise under logs or in tree hollows so that entry was only possible from the front. Plaster cubes soaked in the cat urine and faecal mixture "PONGO" (Algar *et al*. 1999), were placed at the rear of the tray so that an animal would need to place its paws in the tray to investigate. To minimize the possibility of attracting predators into the trapping grid, the scent stations and sand plots were located approximately 20–50 metres outside of the trapping grid. Scent stations were set up each time trapping was conducted, with an additional two sessions in February (summer) 2005 and in July (winter) 2005. Each scent station was examined for a minimum of two nights in each trapping session. Paw prints were photographed and later identified using Triggs (1996).

Trapping data analyses

Trapping data from all sites were compared for community structure and species diversity using the:

- Sorensen similarity index for similarity in presence/absence of species (C)
- Shannon-Weiner indices for comparison of species diversity (H') (we used logarithms to the base 10 in the calculation, so units are in decits)
- Shannon's measure of evenness for comparison of species evenness across the sites (J) (see Krebs 1999 for each analysis)

Brushtail Possums and Southern Brown Bandicoots were the only species found at all sites. The numbers of each of these species known-to-be-alive (KTBA) in each trapping session were also calculated. Although several Mardos were caught at Site A (Stinton Cascades), we did not calculate KTBA, because most recaptures occurred within a single trapping session.

Vegetation structure and floristics at the study sites

Within the single trapping grid at each site, five 2 m × 2 m quadrats were pegged for vegetation survey — one quadrat in each of the four corners of the trapping grid, and one in the centre of the grid. Canopy cover in each trapping grid was measured with a spherical densiometer. One reading was taken in each of the four corners of each of the five quadrats at each trapping grid and averaged to give a single reading per quadrat. All shrubs within the five quadrats at each trapping grid were identified and their percentage cover estimated. Tree density was estimated using a simple point sampling method (University of Minnesota 2002). Readings were taken from the quadrat in the centre of the trapping grid by the same individual. The density of the vegetation was measured in a vertical dimension, because this would have the greatest significance for mammals. A 46 × 38 cm checkerboard comprising squares of 4 × 4 cm, totalling 126 alternating black and white squares, was positioned at ground level in the four corners of each quadrat in each trapping grid. An observer then noted how many of the squares were at least partially obscured by vegetation when looking at the board at ground level from a distance of 2 m. The depth of leaf litter was measured in the four corners of each quadrat in each trapping grid by pushing a 30 cm ruler down to soil level and measuring litter depth in cm.

Floristic similarities between sites were compared with non-metric multi-dimensional scaling (MDS), using the permutation procedures in Primer v5 (Clarke and Gorley 2001). Initially, we converted the percentage cover data for each each quadrat in each trapping grid (a total of five readings per trapping grid) to a Braun-Blanquet scale showing the dominance of each vegetation species based on cover. Then the dominance index of each species was ranked according to the quadrats in which it was found. The Braun-Blanquet figures were then used in the MDS analysis. The MDS procedure begins by calculating similarity matrices for the 20 readings based on grouping individual quadrats into their respective sites (i.e. A, B, C and D) and representing these graphically to reveal patterns in the distributions. It is also possible to test *a priori* hypotheses regarding the grouping of particular points in the MDS, which in this case enabled us to test the hypothesis of similarities between sites in a series of pair-wise tests, with the significance levels corrected using the modified Bonferroni correction (Quinn and Keough 2004).

The possible influences of Site and Quadrat on the structural variables of canopy cover and leaf litter depth were assessed using MANOVA. Site and Quadrat were factors in the design with Quadrat nested within Site. The dependent variables (canopy cover and leaf litter depth) were log-transformed before analysis to correct for heterogeneous variances. We were interested primarily in Site differences. Vertical vegetation densities were 0 at sites B and D, so this variable was analysed with a nested ANOVA with factors of Quadrat and Site (with Quadrat nested within Site and Sites B and D excluded). If any dependent variable in either analysis was significantly different between sites, we then determined the Spearman rank correlation coefficients between the values for each site and the total numbers of individual mammals caught at the sites to see if the variable was related to mammal captures. Tree densities were rank correlated to total numbers of individual mammals caught at the sites to test for possible relationships between these variables.

RESULTS

Trap success

Trap success from Elliott traps was highly variable: 0.21% at Araluen (curfewed cat), 0.63% at Churchman Brook (no cat), 2.1% at Warwick Savage Park (unregulated) and 10.9% at Stinton Cascades (unregulated cat). Brushtail Possums or Southern Brown Bandicoots disturbed many Elliott traps at Warwick Savage Park and Araluen, with the occasional disturbance at Stinton Cascades, probably reducing trap success. Trap success from cage traps was greater overall: 18.4% at Araluen (curfewed cat), 5.3% at Churchman Brook (no cat), 52.9% at Warwick Savage Park (unregulated cat) and 31.6% at Stinton Cascades (unregulated cat).

Animals trapped

Eighty-four mammals from seven species were recorded over 19 nights of trapping across all sites (Table 2). Native and introduced species were found at all sites. One cat was captured at Warwick Savage Park, one of the unregulated cat sites.

To check for the possibility that some small mammals were not trapped at Warwick Savage Park (unregulated cat) because many of the Elliott traps were disturbed by Southern Brown Bandicoots or Brushtail Possums, six extra cage traps were positioned at this site in August 2004 to trap the offending animals. No new species were recorded in the Elliott traps on that occasion, so it is unlikely that disturbance was biasing the range of mammals trapped.

Similarity of mammal communities

The Sorenson coefficients of similarity (C) can range between 0 (no species in common between the sites) to 1 (all species present at both sites). There were strong similarities between Araluen (curfewed cat) and Warwick Savage Park (unregulated cat) (C = 0.86) and between Araluen and Churchman Brook (no cat), (C = 0.75), while Stinton Cascades (unregulated cat) and Warwick Savage Park (unregulated cat) were the least similar (C = 0.50) (Table 3).

Table 2. Species and total number of individuals trapped and recorded at each site. Number recorded does not include recaptures i.e. new individuals only.

Location/Site	Species	No. recorded
(A) Stinton Cascades (Unregulated cat)	Mardo	22
	Brushtail Possum	12
	Southern Brown Bandicoot	6
	Black Rat	1
(B) Araluen (Curfewed cat)	Brushtail Possum	8
	Southern Brown Bandicoot	1
	House Mouse	1
(C) Warwick Savage Park (Unregulated cat)	Southern Brown Bandicoot	14
	Brushtail Possum	8
	House Mouse	3
	Cat	1
(D) Churchman Brook (No cat)	House Mouse	2
	Brushtail Possum	2
	Southern Brown Bandicoot	1
	Echidna	1
	Mardo	1

Comparisons of species diversity of mammals

The Shannon-Weiner species diversity (H') values for mammal captures (Table 4) were not significantly different between sites using the t-test for comparing H' values described in Zar (1999, p. 156–158) and incorporating the modified Bonferroni correction (Quinn and Keough 2004) for the six multiple tests (in all cases, $p > (0.05/6) = 0.0083$). Thus the sites were similar in species diversity. The Shannon evenness for each site (J) can range from 0 (all individuals are from one species) to 1 (individuals are distributed evenly across all species present). At Churchman Brook (no cat), the J value was 0.96 indicating that the abundance of all species was nearly equal. Brushtail Possums dominated at Araluen (curfewed cat), resulting in the lowest J-value of 0.62 (Table 4).

Abundance of trapped species

Numbers of Southern Brown Bandicoots known-to-be-alive (KTBA) at any trap session at each site ranged from 0 animals at Araluen and Churchman Brook (curfewed cat and no cat respectively), to 2–6 individuals at Warwick Savage Park (no cat). For Brushtail Possums the range was smaller, from 0–2 at Churchman Brook to 0–3 at all other sites (Table 5). The total number of individuals trapped (excluding the single cat trapped) was significantly higher at Stinton Cascades and Warwick Savage Park (both unregulated cat) (41 and 25 respectively) than at Araluen (curfewed cat) and Churchman Brook (no cat) (10 and 7 respectively), based on the assumption that capture numbers should be equal across the sites (χ^2_1=29.0, $p < 0.001$).

Scent stations and predator presence

Three prints were found in the sand trays at scent stations: a Southern Brown Bandicoot was detected at Stinton Cascades (unregulated cat) and a Brushtail Possum and a cat were detected on separate occasions at Warwick Savage Park (unregulated cat).

Vegetation structure and floristics

We recorded 56 plant species across all sites and the total number of individual plants found ranged from 54 (in site B, Araluen) to 253 (in site A, Stinton Cascades). The most common plant species found in all four sites were Jarrah, Wood Mat Rush *Lomandra sonderi* and *Pentapeltis peltigera*.

The 2-dimensional MDS calculated for the Braun-Blanquet values indicates dissimilar vegetation floristics at the sites (Figure 2). Pairwise tests based on MDS and incorporating the modified Bonferroni correction found that all pairs of sites were significantly different in vegetation ($p < 0.024$ or less for each comparison), with the exception of sites B (Araluen) and D (Churchman Brook) ($p = 0.23$). MANOVA using factors of site and quadrat (with quadrat nested within site) and log-transformed

Table 3. Sorensen's similarity indices for comparison of mammal communities at each site.

Sites Brook	(A) Stinton	(B) Araluen Cascades	(C) Warwick	(D) Churchman Savage Park
(A) Stinton Cascades (unregulated cat)	–	0.57	0.50	0.67
(B) Araluen (curfewed cat)		–	0.86	0.75
(C) Warwick Savage Park (unregulated cat)			–	0.67
(D) Churchman Brook (no cat)				–

Table 4. Shannon-Weiner diversity indices (H') and evenness indices (J) for each site. No pair of sites is significantly different in H'.

Sites	**SW (H')**	**J (H'/H'max)**
(A) Stinton Cascades (unregulated cat)	0.46	0.77
(B) Araluen (curfewed cat)	0.30	0.62
(C) Warwick Savage Park (unregulated cat)	0.46	0.77
(D) Churchman Brook (no cat)	0.67	0.96

Table 5. KTBA of Southern Brown Bandicoots and Brushtail Possums at five trapping sessions in each site. The KTBA is given for the end of each trap session, which consists of four nights from each site (except for Session 5, where there were only three nights).

	Trap session				
Species and site	**1**	**2**	**3**	**4**	**5**
Southern Brown Bandicoot					
(A) Stinton Cascades (unregulated cat)	0	0	0	2	1
(B) Araluen (curfewed cat)	0	0	0	0	0
(C) Warwick Savage Park (unregulated cat)	0	2	6	4	0
(D) Churchman Brook (no cat)	0	0	0	0	0
Brushtail Possum					
(A) Stinton Cascades (unregulated cat)	0	2	3	3	0
(B) Araluen (curfewed cat)	0	2	2	3	2
(C) Warwick Savage Park	0	0	3	3	1
(D) Churchman Brook (no cat)	0	0	0	0	2

dependent variables of percentage of canopy cover and depth of leaf litter (Table 6), found significant differences across sites and quadrats ($p < 0.001$ in each case), with canopy cover significantly different between sites and between quadrats ($p < 0.001$ in each case). Leaf litter was significantly different between quadrats ($p < 0.001$) but not sites ($p = 0.07$). Nested ANOVA of the dependent variable of vertical density data using factors of site (sites A (Stinton Cascades) and C (Warwick Savage Park) only) and quadrat (with quadrat nested within site), found that vertical density differed between sites ($p < 0.001$) but not between quadrats ($p = 0.71$).

Given that canopy cover and vertical vegetation density differed between sites, rank correlation coefficients were used to test for any possible relationship with total mammal captures at each site. Total mammal captures did not correlate significantly with either canopy cover ($R_4 = 0.80$, $p = 0.20$) or vertical canopy cover ($R_4 = 0.95$, $p = 0.05$), although the latter result is statistically borderline.

Sites A (Stinton Cascades) and C (Warwick Savage Park) had the highest tree density, estimated at 33 trees per hectare followed by site B (Araluen) with 26.4 trees per hectare, while site D (Churchman Brook) had the lowest density (6.6 trees per hectare). Tree density did not correlate significantly with total mammal captures ($R_4 = 0.95$, $p = 0.05$).

DISCUSSION

We predicted that the no cat and curfewed cat sites (Churchman Brook and Araluen) should be more similar in mammal species composition to each other than to unregulated cat sites (Stinton Cascades and Warwick Savage Park), and that mammal species diversity and abundance should be higher at the no cat and curfewed cat sites compared to unregulated cat sites. These predictions were not fulfilled. The strongest similarity in species composition was between Araluen (curfewed cat) and Warwick Savage Park (unregulated cat). No significant differences in species diversity were found across the sites and KTBA statistics for Brushtail Possums and Southern Brown Bandicoots were similar across all sites. The Mardo, which could be regarded as the most susceptible to cat predation of all the native species trapped because of its size, was trapped mostly at Stinton Cascades (unregulated cat). Total mammals trapped at the

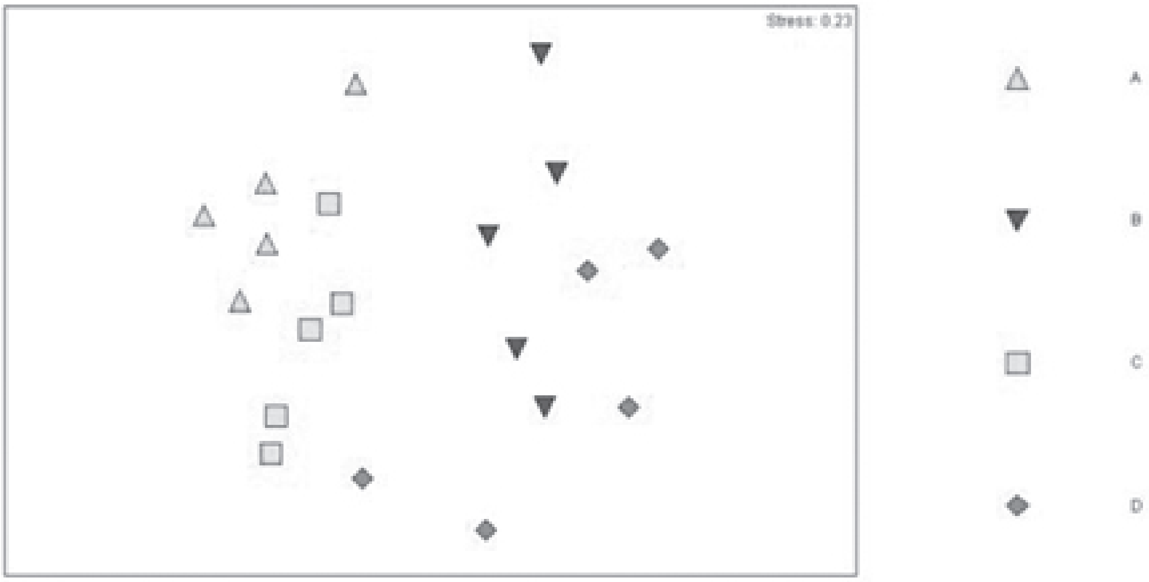

Fig. 2. 2. Dimensional MDS grouping of vegetation communities in all sites based on Braun-Blanquet indices, indicating distinct vegetation groupings at each site. A – Stinton Cascades, unregulated cat, B – Araluen Estate, curfewed cat, C – Warwick Savage Park, unregulated cat, D – Churchman Brook Estate, no cat

Table 6. Means and standard errors of canopy cover (%), leaf litter depth (cm) and vertical vegetation density for each site.

Site	Mean Canopy cover (%) ± SE	Mean Leaf litter (cm) ± SE	Vertical vegetation density (squares covered) ± SE	N
(A) Stinton Cascades (Unregulated cat)	78.2 ± 2.4	1.7 ± 0.2	23.8 ± 8.0	20
(B) Araluen Estate (Curfewed cat)	77.8 ± 3.6	2.0 ± 0.7	0.0 ± 0.0	20
(C) Warwick Savage Park (Unregulated cat)	72.3 ± 3.6	2.7 ± 0.5	2.3 ± 0.8	20
(D) Churchman Brook Estate (No cat)	62.2 ± 5.2	1.4 ± 0.3	0.0 ± 0.0	20

unregulated cat sites exceeded those caught at the curfewed cat and no cat sites. It appears that pet cats are not the major influence on the community composition, species diversity or abundance of small and medium-sized mammals at these sites. These results agree with those of Kays and DeWan (2004), who found no relationship between number of cats detected and local small mammal abundance in a nature preserve in New York State, USA.

One possible explanation for the absence of any effect of cat restrictions is that they were often unenforced, so pet cats at all areas were venturing into the reserves and impacting wildlife. We consider this unlikely, because we detected only one cat at a scent station (Warwick Savage Park), which was probably the same individual trapped at that time. It was not collared or microchipped, but we believe it was a stray and most probably a dumped pet. Crooks (2002) and Kays and DeWan (2004) confirmed that, on average, domestic cats are more abundant within 100 m of urban edges and rates of visitations to scent stations by pet cats decrease with distance from urban edges (see also Lilith *et al*. 2008 for a recommendation of buffer zones of 360 m to prevent pet cat incursions into reserves). Given that our grids were all located within 20–30 m of the edges of the reserves, pet cats should have been able to reach them. We conclude that irrespective of enforcement of regulations, we have little evidence of pet cats roaming around our trapping grids. Fauna at our study sites may be more at risk from feral predators such as Red Foxes *Vulpes vulpes* or feral cats than from pet cats, although it may be that our sampling intensity was not high enough to detect activity by pet cats.

A second possibility is that vegetation differences between the sites masked any effect of cat predation. Mammal captures were significantly higher at Stinton Cascades and Warwick Savage Park (unregulated cat), but the vertical vegetation was significantly denser compared to the other two sites (curfewed cat and no cat). We also found a borderline ($p = 0.05$) result for a rank correlation between vegetation density and mammal captures. Denser vegetation provides greater shelter from predators and often richer food resources. For example, Claridge and Barry (2000) found that diggings of bandicoot species in eastern Australia increased with increased ground cover vegetation. Resident adults tended to occupy vegetation that was well concealed, while dispersing individuals and/or subadults occupied the more open patches of vegetation. Similarly, Vernes (2003) found that the Northern Brown Bandicoots *Isoodon macrourus* in his study preferred habitats with dense ground cover, while Buckmaster *et al*. (2010) found that native terrestrial small mammals were more likely to persist in urban reserves in Canberra, Australian Capital Territory, where vegetation litter levels and fallen logs > 10 cm in diameter were higher. Even arboreal possums may benefit from denser ground cover if forced to the ground to move between trees (Jones and Hillcox 1995), or to move from remnant bushland to access resources in neighbouring suburbs (Harper *et al*. 2008). More recent studies confirm that the responses of small and medium sized Australian mammals to habitat features can be complex and subtle (Claridge *et al*. 2008, Southwell *et al*. 2008), including responses to changes in vegetation caused by plant disease (Garkaklis *et al.* 2004), so the denser vegetation at Stinton Cascades and Warwick Savage Park may have reduced the risk of predation or altered habitat desirability in other ways, preventing an effect of cat restriction appearing.

Finally, in relation to the impact of pet cats on bird species richness in suburbia, Grayson *et al*. (2007) suggested that the impact of pet cats may occur quickly in new subdivisions, with susceptible species disappearing early so that subsequent studies show no effect of predation by pet cats. We believe that this is unlikely to be a factor in the current study, because mammals at Churchman Brook were never exposed to pet cats from the local housing estate and represent an effective control for an early extinction effect after development.

On balance, we found no evidence that regulation of pet cats was important in determining the presence or abundance of small mammals in our study sites. Instead, vegetation characteristics were probably the greatest influence. However, it is important to bear in mind the limitations of the work. In particular, there were no data collected before cat regulations were enforced, so changes in the species diversity and abundance of small mammals in response to the regulations imposed on pet cats is unknown, although the Churchman Brook site where pet cats were never permitted provides some indication of the "before" scenario. The number of reserves sampled was also moderate. Furthermore, while pet cats may not influence the presence/absence of species, cats' preferences for moving along tracks or vegetation edges may make these areas a barrier for small mammal dispersal (Kays and DeWan 2004). Therefore in disturbed habitats, such as those with less vegetation cover, the presence of cats may impact on recolonization of locally endangered species such as the Mardo. They may also interfere with mammals that would otherwise move between remnants and adjoining suburbia.

Based on some of the difficulties we encountered, future studies investigating the potential impacts of roaming pet cats in urban and peri-urban reserves could benefit from more detailed assessments of vegetation structure and perhaps more sites. Our borderline results for the impact of vegetation might have been clearer if sampling had been more intensive. Nevertheless, as the number of studies accumulates, there may be opportunities for meta-analyses that combine the results of several studies to test hypotheses more rigorously. Consideration could also be given to translocation/reintroduction studies conducted to experimental protocols, where the fate of translocated animals is monitored in relation to the presence/absence of roaming pet cats (see, for example, Winnard and Coulson 2008 for a call to study causes for the outcome of translocations in relation to the Eastern Barred Bandicoot).

Despite our negative results, we do not believe that regulations on pet cats should be relaxed. There is clear evidence of their predatory impacts on Eastern Barred Bandicoots in Hamilton, Victoria (Dufty 1994) (although we do note that this study also ascribed very high mortality to road traffic and there seems to be more enthusiasm to regulate cats than there is to regulate cars). Our study also says nothing of the possible influence of pet cats on other taxa such as birds or reptiles, nor of the capacity of pet cats to disseminate wildlife diseases such as toxoplasmosis (Dabritz *et al*. 2007) or sarcocystis (Stanek *et al*. 2003). However, given the weakness of the case for predatory impacts, proponents of regulation may improve acceptance by basing their arguments on grounds of animal welfare and community relations. Studies in the UK indicate a high risk of fighting and road accident trauma for free-roaming cats (Rochlitz 2003a,b, 2004), and there is limited evidence from Australia too (Calver *et al*. 2007). Red Foxes in Australian reserves might kill pet cats as well (Coates 2008). Free-roaming cats may also cause considerable community nuisance for non-cat owners and cat owners alike by fighting, spraying and fouling gardens (see review by Grayson and Calver 2004). There is general community support in Australia for measures such as restricting the number of cats per household, tagging, neutering and nocturnal confinement that might curb predatory impacts (Grayson *et al*. 2002, Lilith *et al*. 2006), although implementing measures is challenging for municipal authorities (Kelly 1999).

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