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Original Research Article

Ultrasonic deterrents reduce nuisance cat (*Felis catus*) activity on suburban properties

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A B S T R A C T

Urban environments are increasingly important for biodiversity conservation, but pet cats threaten wildlife therein, displaying nuisance behaviour such as hunting, fighting, fouling and urine spraying. In an attempt to empower landholders wishing to reduce cat incursions humanely, we tested the effectiveness of two ultrasonic cat deterrents (CatStop© and On-Guard Mega-Sonic Cat Repeller©).

After confirming in arena trials that cats detect and respond negatively to an ultrasonic device, we tested both deterrents in 18 suburban gardens in Perth, Western Australia. Camera monitoring at foci of cat activity (e.g. fish ponds, property entry/exit points) occurred for two weeks before (Period 1: device off), during (Period 2: device on) and after (Period 3: device off) the activation of deterrents. Data included individual cat demographics and behaviours, number of cat detections per site per day per sampling period, the duration of cat activity, and detection of non-target species.

Seventy-eight unique cats were detected at 17 of 18 garden sites (2–9 cats/garden). Over half the cats could be sexed (56.4%, with 65.1% males). Nearly 53.0% of cats were confirmed to be pets living nearby. Cats that were most active in period 1 ($\geq$100 s total activity duration) were classified as 'residents'; all others were 'peripherals'.

Overall, the ultrasonic deterrents reduced the frequency of incursions into gardens by resident cats by 46%, while the duration of incursions was reduced by 78%. Cat activity declined significantly from period 1 (baseline) to period 2 for resident cats but not peripheral cats (50% reduction; $p = 0.001$), and remained depressed in period 3 for resident cats but not peripheral cats ($p < 0.001$). Peripheral cat activity remained at an unchanging low level across all three periods. Males were slightly more active than females over the experiment ($p = 0.04$), but sexes did not vary in response to deterrents ($p > 0.05$). Cats confirmed as owned (53% of cats) generated more activity than cats of unknown ownership status ($p = 0.03$), probably reflecting proximity of their residences to trial gardens. Both deterrent models had similar effects ($p = 0.89$).

By allowing pets to roam, cat owners are complicit in cat nuisance. This requires public education. Ultrasonic deterrents offer a cost-effective, humane option to reduce incursions by unwanted cats. Ultrasonic deterrents will not prevent all incursions, but they reduce their frequency and duration. Reduced cat activity has flow-on benefits to wildlife across a variety of urban-suburban settings, including gardens and parks.

Abbreviations: CS, CatStop Ultrasonic Cat Deterrent©; OG, On-Guard Mega-Sonic Cat Repeller©; AUD, Australian Dollar.

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1. Introduction

Wildlife conservation in cities presents a paradox. On the one hand, as human modification of landscapes intensifies, urban and suburban environments are growing in importance for biodiversity conservation (Ives et al., 2016). Gardens, parks and small reserves provide habitat for resident and migratory wildlife, while encouraging human residents to interact with greenspaces and wildlife (Cox and Gaston, 2016; Daniels and Kirkpatrick, 2006; Fernández-Juricic and Jokimäki, 2001; Nielsen et al., 2014). On the other hand, the most popular pets in cities are dogs (*Canis familiaris*) and cats (*Felis catus*) that may threaten urban wildlife (Baker et al., 2010).

Interactions between pet cats (those fully dependent on a human household but wandering at will), semi-feral cats (partially provisioned by people and including what some authors term 'stray cats' or 'feral cats') and wildlife in cities are especially contentious because of the value placed on cats as companion animals, and the risk posed by their predatory behaviour (Baker et al., 2010; Calver et al., 2011; Mameno et al., 2017). The popularity of cats as companion animals is increasing, with cat ownership approaching that of dog ownership in many countries (AMA, 2016; FEDIAF, 2014) and even surpassing dogs in New Zealand (NZCAC, 2016) and the United States of America (APPA, 2015–2016). Cat densities increase with human density, such that cities support cat numbers >100/km^2 (Liberg et al., 2000). Densities of semi-feral cats are particularly high where there is uncontrolled breeding (e.g. 344–976 cats/km^2 across Tel Aviv, Israel, Finkler et al., 2011a), and ample food subsidies (human garbage, Mirmovitch, 1995; feeding strays, Natoli et al., 1999). People also form bonds with semi-feral cats (Toukhsati et al., 2012; Zasloff and Hart, 1998; Zito et al., 2015), leading to establishment of legal and illegal cat colonies in many cities (Aguilar and Farnworth, 2013; Mameno et al., 2017; Tan et al., 2017).

Regardless of ownership status, roaming cats threaten wildlife through predation (Hall et al., 2015; Loss et al., 2013; Loyd et al., 2013a; McRuer et al., 2017), disease transmission (Hellard et al., 2011) or sub-lethal effects such as avoidance-through-fear (Beckerman et al., 2007; Bonnington et al., 2013; Dauphiné and Cooper, 2009). Cats also threaten human health by transmitting pathogens and parasites (e.g. *Toxoplasma gondii*, Dabritz and Conrad, 2010; *Toxocara cati*, Alonso et al., 2001; rabies and plague, Taetzsch et al., 2018; Yamaguchi et al., 1996); endanger their own welfare from road accident trauma (Rochlitz, 2003a, 2003b), accidental poisoning (Xavier et al., 2002), disease transmission (Feline Immunodeficiency Virus, Natoli et al., 2005), fighting (Calver et al., 2007; Finkler et al., 2011b), larger predators such as coyotes (*Canis latrans*, Gehrt and Riley, 2010), exploring dangerous locations (Loyd et al., 2013b) and encountering human persecution (Vnuk et al., 2016). Cats also cause significant nuisance for property owners, cat owners and non-cat owners alike (e.g. urine spraying, caterwauling, Uetake et al., 2014).

Despite extensive research into these issues, state and municipal authorities may be unwilling to legislate total confinement of pet cats because of perceptions of cruelty (Sandøe et al., 2017), or because some restrictions are unpopular with small but vocal groups of cat-lovers (Marra and Santella, 2016). With regard to semi-feral cats, lethal control is accepted in some scenarios (Lohr et al., 2013; Lohr and Lepczyk, 2014; Lohr et al., 2014) but can be controversial in others (Mameno et al., 2017; Peterson et al., 2012), while Trap-Neuter-Release is also divisive, because although no cats are killed, desexed cats remain in the environment and the success of the method in reducing cat numbers is disputed (for alternative views, see Longcore et al., 2009, Spehar and Wolf, 2018). Therefore, individual householders seeking to reduce nuisance or enhance wildlife protection by discouraging cat incursions onto their properties need affordable, humane strategies that mitigate human-feline conflict at the local, individual citizen level.

Commercially available ultrasonic deterrents may be appropriate for use against encroaching cats in domestic suburban gardens. Cats have evolved an extremely broad hearing range and are particularly sensitive to high-frequency sounds (6.6 octaves, 0.5–32 kiloHertz, Heffner and Heffner, 1985), similar to vocalisations made by their rodent prey (Portfors, 2007). Consequently, cats triggering the motion sensors of ultrasonic deterrents receive a blast of ultrasonic sound intended to evoke alarm and flight. Nelson et al. (2006) found that the Catwatch© ultrasonic device reduced the probability of incursions by approximately 32.0% and the duration of incursions by up to 38.0% in a United Kingdom suburban setting. Mills et al. (2000) reported that the Pestaway Champ© ultrasonic device did not cause physical or enduring pain, although they found no evidence of a deterrent effect in a test arena setting.

With the explicit goal of empowering private property owners with a low-cost humane solution to nuisance cat activity, including cases where nuisance cats hunt wildlife, ultrasonic deterrents were trialled in two stages. Firstly, in a controlled setting we established whether: 1) cats detected the ultrasonic sound produced by a commercial deterrent, and 2) cat reactions were positive, neutral or negative. Secondly, trials against roaming cats were carried out in domestic gardens of landholders who reported regular nuisance cat activity. Garden trials utilised a Before-During-After experimental design to confirm whether: 3) cats reduced their activity in gardens when deterrents were activated. We extended the work of Nelson et al. (2006) by following their suggestions for improving the placement of devices, as well as using motion-sensitive cameras to automate continuous monitoring of cat incursions as an alternative to landholder perceptions of cat activity over specified short monitoring periods.

2. Methods

2.1. Study area

All studies were carried out in the city of Perth, capital of the state of Western Australia, and fourth largest city in Australia (ABS, 2016a). A population of 2.02 million inhabits a land area of 6,420 km^2 (ABS, 2016b). Suburban developments are extensive with 77.1% of people living in houses, 16.0% in townhouses and 6.9% in apartments/other.

Table 1
Specifications of CatStop© and On-Guard© ultrasonic deterrents trialled in controlled and field settings. Included for comparison are specifications of devices tested by Nelson et al. (2006), and Mills et al. (2000). kHz: kilo Hertz NS: Not Specified.

Deterrent	Ultrasonic frequency	Detection angle	≈ Protected area	≈ Max. trigger distance	Power source
CatStop Ultrasonic Cat Deterrent©	Sound cycles 21–23 kHz	80°	28m^2	6m	9 volt battery with mains connection accessory
OnGuard Mega-Sonic Cat Repeller©	Sound cycles 18–27 kHz	98°	123m^2	12m	2 × 9 volt batteries with mains connection accessory
Catwatch© Ultrasonic Deterrent	Sound cycles 21–23 kHz	100°	NS	12m	NS
Pestaway Champ©	Sound cycles 19–30 kHz every 15 s	NS	NS	Tested at 4m	NS

Perth lies within the South-West Botanical Province (extending 26° − 36° south, 114° − 126° east) one of 25 global biodiversity hotspots (Myers et al., 2000). Vertebrate fauna includes 54 mammals (10 endemic spp.), 231 birds (14 endemic spp.), 174 reptiles (54 endemic spp.), 32 frogs (27 endemic spp.) and eight fish species (all endemic; Rix et al., 2015). Perth, in common with other Australian cities, supports nationally threatened flora and fauna (Ives et al., 2016), with many animal species directly threatened by introduced predators such as cats and European red foxes *Vulpes vulpes* (Calver et al., 2007; Coates and Wright, 2003; Hall et al., 2015).

2.2. Devices tested

The CatStop Ultrasonic Cat Deterrent© (CS, Contech Enterprises Inc. Canada: www.contech-inc.com), and On-Guard Mega-Sonic Cat Repeller© (OG, Defenders U.K.: www.stvpestcontrol.com) are commercially available ultrasonic deterrents. Devices are priced under $100.00 AUD and come with plastic stakes for ground mounting. Passive infra-red motion detectors trigger when cats enter a ‘protection zone’ in front of the unit. The CS and OG differ in technical specifications (Table 1) but claim to prevent nuisance behaviour by developing negative associations with unit location.

2.3. Part 1: cat behaviour arena trials

2.3.1. Arena trial setup and shelter cats

Arena trials of one model of ultrasonic deterrent (CS) were carried out on domestic cats on the premises of the Cat Haven (www.cathaven.com.au), Western Australia's largest cat shelter. To ensure that a range of cat ages, temperaments and sexes were included in device trials, shelter staff selected 12 desexed, common domestic shorthair cats according to age (Kitten < 1 year, Adult 1–7 years, Mature > 7 years, n = 4 each category), sex (Female, Male n = 6 each), and temperament (Bold, Shy, n = 6 each). No sexually intact or pure breed cats were available at the time of the trial.

Cats were individually placed in a soft-netted enclosure (2m × 2m x2m) with bedding, food and water, litter tray and ‘hide’ box placed in corners to accommodate natural behaviours. After an initial 20-min adjustment period in the enclosure, four Samsung© HMX-F90 video cameras filmed cats continuously for two 10-min periods (Period 1 − CS off, Period 2 − CS on). During period 2 the CS was triggered manually every minute by an operator behind a screen. To eliminate issues of directional habituation, the deterrent was triggered from one of two locations, at either 1m or 6m distances from the enclosure (6m maximum detection range of CS). Two cats were randomly selected as controls and were not exposed to an active deterrent during period 2.

Video footage was then scrutinised to assess individual cat behaviours. Using Rodan (2012) as a guide, a straight-forward anxiety-spectrum was developed that corresponded with five typical cat arousal states (Fig. 1). At the end of periods 1 and 2, the total number of times a cat exhibited particular arousal states was tallied. Cats were classified as having detected the ultrasonic deterrent if their ears, heads and/or body swivelled to face the direction of the CS after triggers. Reactions were classified as: positive if cats approached the CS; neutral if no change in behaviour was detected; or negative if anxious/fearful behaviours increased in frequency. Expression of typical ‘stress behaviours’ was also taken to indicate negative reactions to deterrent stimulus, and included: displacement autogrooming (van den Bos, 1998); retreating into a hide (Vinke et al., 2014); and defensive vocalisations (e.g. hiss, Ley and Seksel, 2012).

2.3.2. Statistical analysis

Given the small number of cats in the trial we did not discriminate between ages, temperaments and sexes, but regarded inclusion of representatives of all types as protection against bias from one or more of these factors. Not all categories of arousal behaviour were exhibited over the trial periods, so categories were combined for analysis into ‘Negative’ (Anxious, Fearful) or ‘Other’ (Relaxed, Curious, Alert). We analysed the relative behaviour frequencies for control and treatment cats across periods 1 and 2 using a three-way log-linear analysis in VassarStats (www.vassarstats.net). The levels of analysis were observation period (Periods 1, 2), behaviours (Negative, Other) and device activity status (Period 1 − CS off for control and

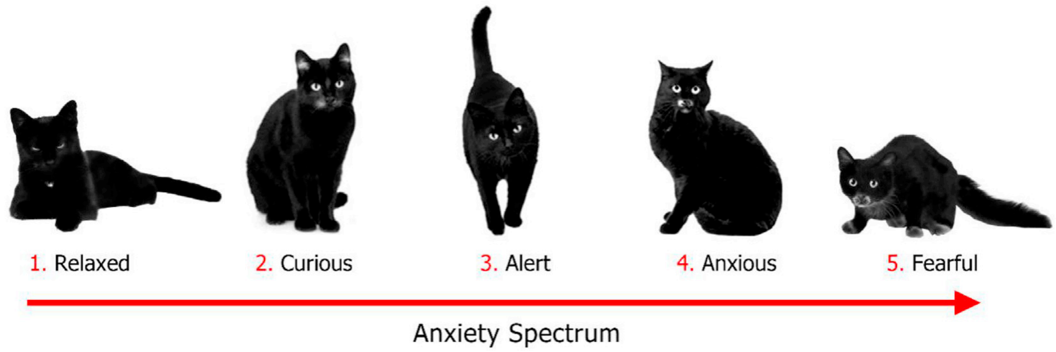

Fig. 1. Cat behaviours expressed during arena trials were classified according to a simple anxiety-spectrum that correlates with five typical cat arousal states that have predictable body postures (loosely based on Rodan, 2012).

treatment groups, Period 2 – CS off for control group but on for treatment group). We reasoned that if CS increased the frequency of negative behaviours relative to other behaviours in treatment cats only, there should be a significant three-way interaction ($p < 0.05$) between all factors in the analysis.

2.4. Part 2: domestic garden trials

2.4.1. Recruitment of volunteers

To trial ultrasonic deterrents on cats in the field, an advertisement requesting volunteers was placed on the Birdlife Western Australia (www.birdlife.com.au) social media page. Volunteers needed to meet three criteria: 1) there was weekly cat activity in their garden; 2) gardens were available for a continuous six-week trial; and 3) no outdoor pets were owned which might come into contact with devices (e.g. dogs, aviary birds). Eighteen garden properties from across the wider-metropolitan area met these criteria and were included in the trial (Fig. 2).

2.4.2. Setup of ultrasonic deterrents and monitoring cameras

A limited number of cameras and deterrents were available for trials, so to increase likelihood of detecting cat activity, potential properties were inspected for foci of cat activity including fish ponds, sand pits, urine spray points, scratch-marking trees and property entry/exit points (Fig. 3, Figs. A1, A2). The two ultrasonic deterrent models were randomly assigned to gardens (CS – 10 sites, 19 devices; OG – 8 sites, 15 devices). Two devices were paired with two cameras at 16 garden sites; one CS was set up with a single camera in garden 17; and garden 18 had an OG with single camera (Supp. Table A1). RECONYX© HyperFire Professional PC900 cameras were tied to trees or wooden posts overlooking foci of activity. Ultrasonic devices were placed in front of cameras so as not to block view of foci of activity. Cameras were active throughout trials, and set to take 3–5 images/second to maximise detection of rapidly-moving cats (colour day images, black and white night images). Trials were designed as Before-During-After experiments and were conducted over three consecutive two-week sampling periods (Sampling Periods 1, 2, 3) with deterrents activated in period 2. Sampling periods were not synchronous across all sites (Supp. Table A2), so environmental effects were random in relation to any particular stage in the study at any individual site. Cameras were active throughout trials and set to take 3–5 images/second to maximise detection of rapidly-moving cats (colour day images, black and white night images).

2.4.3. Data processing

For each sampling period and each individual cat, three measures of activity were calculated from camera images: number of trap events, duration of trap events and number of days detected. For gardens with two cameras, images of cats were pooled. Images were then chronologically organised and assigned to individual cats. Images of individuals were then grouped into independent trap events, defined as the number of images taken from the first to final second of detection. Several cats were active on properties across the day and/or night; therefore, a new trap event began if 5 min or more elapsed between the end of one trap event and subsequent redetection of the same cat. The total number of trap events varied from 1 to 48/period (see Table 2 for examples). The duration of each trap event was calculated using the time-stamp on images and varied from 2 to 4159 s/period. Total number of days each cat was active was also tallied and varied from 1 to 14 days/period.

2.4.4. Cat demographics

Individual cats were identified using breed, pelage pattern and length, body condition, approximate age category (juvenile, adult) and individual markers (e.g. ripped left ear). Some cats could be identified as male or female based on sex-specific

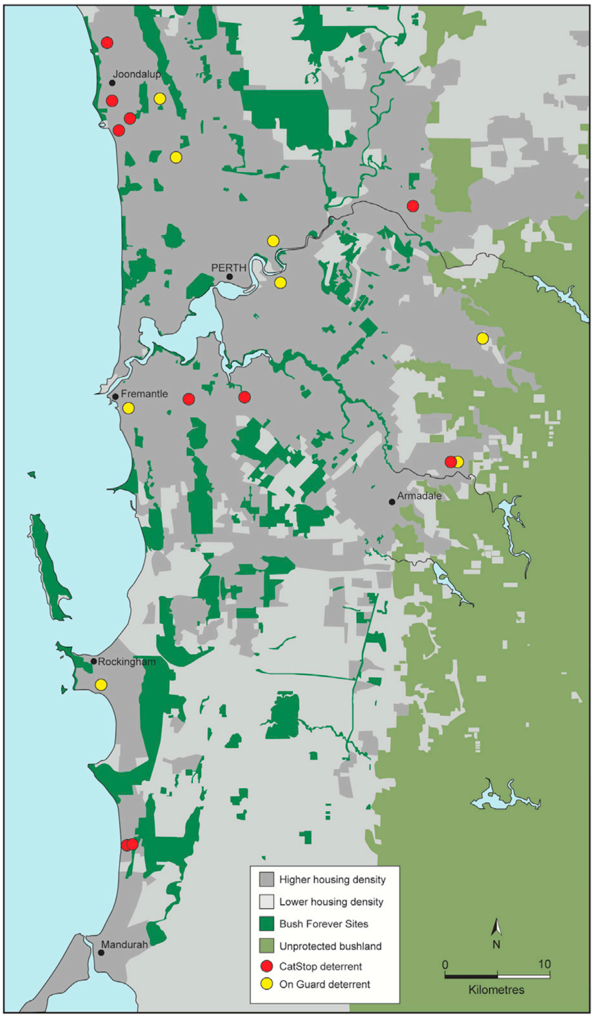

Fig. 2. Perth, Western Australia, and the location of 18 trial site gardens across the wider metropolitan area.

pelage pattern (e.g. ginger, tortoiseshell; Robinson, 1991). Coloured collars were also accepted as indicators of cat sex (pink – females, blue – males); only five females and four males were sexed solely on collar colour. Sexually intact males were identified from images of the scrotum. If cats did not have sex-specific pelages or visible genitals, then their sex was classified as 'Unknown'. Cat body condition was visually graded out-of-three by assessing the fullness of abdomen and neck regions as well as rib visibility (Fig. 4, adapted from Royal Canin© Cat Body Condition www.royalcaninhealthyweight.co.uk/pet-obesity). Cat demographics were confirmed where possible with information from garden volunteers. Cats wearing collars and/or known to reside near trial gardens were classified as 'Owned'. In high density areas, cats establish overlapping home ranges (Bradshaw et al., 2012); therefore, to evaluate whether devices deterred some cats only to be replaced by others, cats that were more active than others in period 1 (≥100 s total duration) were classified as 'Residents'. All others were classified as 'Peripherals'.

2.4.5. Statistical analysis

We first examined the relationships between our cat activity metrics (total events, event duration, number of days active per period); all three metrics were highly correlated (Spearman's rank correlation coefficient, events vs. duration, $r_s = 0.91$; events vs. days, $r_s = 0.99$; and duration vs. days, $r_s = 0.89$). Therefore, we focused our analysis on total number of trap events because it conformed most closely to the underlying assumptions of linear regression. We present means and 95.0% confidence limits for trap events. Lack of confidence interval overlap was interpreted as strong evidence of a difference between groups, and confidence interval overlap but not including the mean was interpreted as moderate evidence. Evidence of an effect for statistical tests was set to the traditional 0.05 level.

Our principal model to determine the effectiveness of the deterrent devices across the study sample of cats was to evaluate count of trap events per day as a function of the main effects: deterrent status (Period 1, 2 or 3), deterrent type (CatStop,

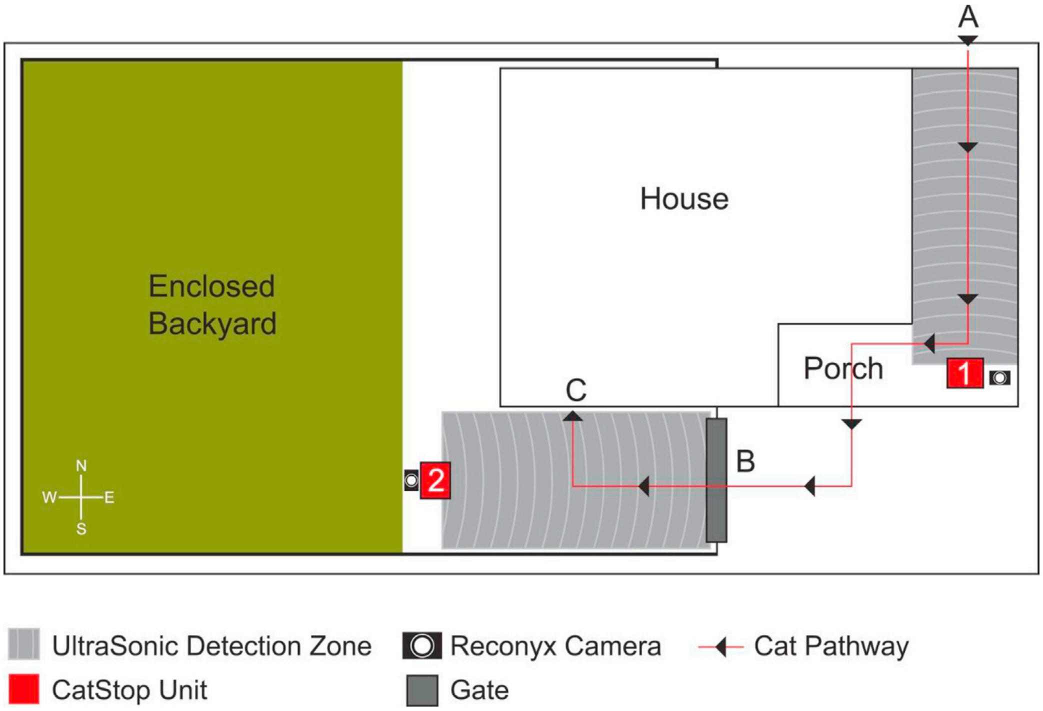

Fig. 3. Example of domestic garden trial site in Perth, Western Australia (property size 381 m^2, Supp. Table A1). Two monitoring cameras were paired with two ultrasonic deterrents and setup overlooking cat activity foci. Cat pathway in foci – the resident cat regularly entered the property at point *A*, walked along the porch (Fig. A1) then down the path at the side of the house to a gate-point B, over which the cat jumped then entered the space under the house-point C (Fig. A2).

Table 2
At each garden site in Perth, Western Australia, camera images were assigned to individual cats and used to determine three measures of cat activity. Example garden shown.

Cat ID	Sampling Period 1 Device OFF			Sampling Period 2 Device ON			Sampling Period 3 Device OFF		
	Number Days	Number Events	Seconds Duration	Number Days	Number Events	Seconds Duration	Number Days	Number Events	Seconds Duration
1	5	7	180	3	2	10	4	4	67
2	5	4	73	2	1	18	2	3	32

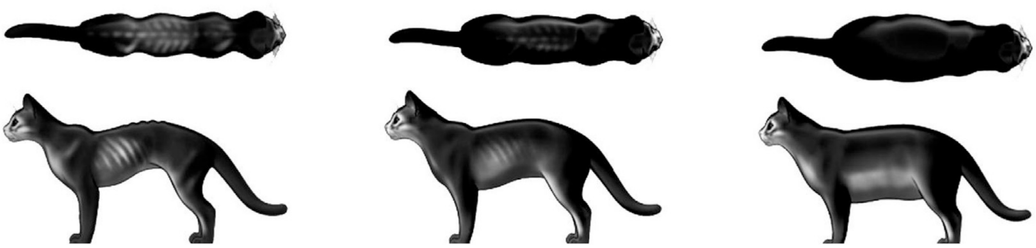

Fig. 4. Lateral and dorsal views of cat body conditions (adapted from Royal Canin© Cat Body Condition). Classified, left to right, as 1) thin, 2) healthy, and 3) heavy.

OnGuard), cat sex (Male, Female, Unknown), transience (Resident, Peripheral) and ownership status (Yes, Unknown). For the main effects we examined two-way interactions of period by sex, period by transience and period by ownership status, retaining interactions where statistically significant. We used an additive mixed-effect hierarchal model with a Poisson distribution to evaluate evidence for main effects and the two-way interactions, while assigning random effects for repeated measurements of individual cats and gardens. Visual assessment of residuals and QQ plots was carried out to assess model fit

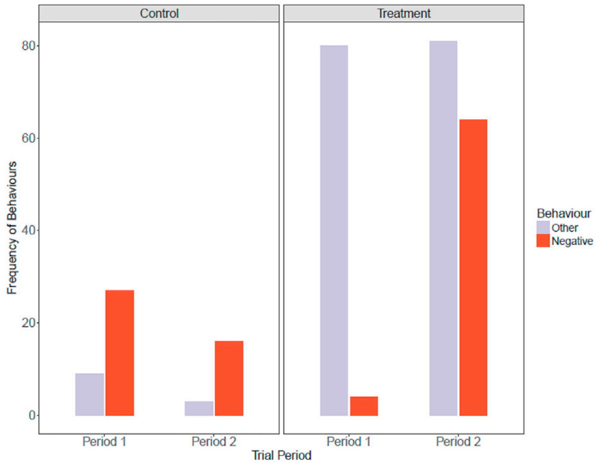

Fig. 5. Arena trials of ultrasonic deterrent effect on cat behaviour. Frequency (total count) of negative behaviours vs. other behaviours exhibited by two control cats and 10 treatment cats during period 1 (10 min with ultrasonic deterrent switched off for all cats) and period 2 (10 min with deterrent switched on for treatment cats only).

and assumptions; no violations of assumptions of normality were detected. Given the explicit hypotheses that we were testing we did not apply a model selection framework. All analyses and data visualisations were carried out using lme4 and ggplot2 packages within R Studio and R version 3.4.4 (R Core Team, 2018; Bates et al., 2015; Wickham, 2016).

3. Results

3.1. Part 1: cat behaviour arena trials

Video footage of cat behaviour during arena trials showed that the two control cats decreased their frequencies of negative behaviours between period 1 and period 2 (Fig. 5), though the two cats varied in the extent and type of changes. One cat did not relax entirely, remaining alert and inside the hide box for both periods. However, the cat's regular stress vocalisations decreased in period 2, as did active surveillance of its surroundings. The second cat became increasingly relaxed as time passed, eventually lying out in the open, in the middle of the enclosure, surveying his surroundings very occasionally. In contrast to control cats, all 10 treatment cats responded to stimuli from the CS ultrasonic deterrent, changing the orientation of their ears and/or head and body to face the direction from which the sound originated. Negative behaviours were exhibited after each trigger of the deterrent, with some cats temporarily freezing in position or crouching low to the ground, and others quickly moving around the enclosure looking for an escape route. Additionally, all cats exhibited more than one typical stress behaviour during period 2 (displacement autogrooming, hiding in hide box, vocalising; Fig. 5). Log-linear analysis confirmed a three-way interaction, with the increase in negative behaviours across treatment cats significant in comparison to control cats and related to activity status of the ultrasonic deterrent ($G^2 = 207.2$, d.f. $= 4$, $p < 0.001$).

3.2. Part 2: domestic garden trials

3.2.1. Physical characteristics and behaviours of cats detected

During garden trials, 78 cats were detected at 17 of 18 garden sites (2–9 cats per garden, total 7421 images of cats, Table 3). Cat breeds included one Persian, 58 short- 15 medium- and 4 long-haired common domestics. Over half of detected cats could be sexed (56.4%), with at least one reproductive cat at 12 of the 17 properties. The physical condition of nearly all cats was healthy or heavy (76 of 78, 97.4%). Collars were worn by 33.3% of cats and, when combined with volunteer information, at least 41 cats were known to be owned (52.6%; Supp. Table A3).

Twenty-six resident cats were identified at 13 gardens in period 1. Resident and peripheral cats displayed behaviours such as urine scent-marking, scratch-marking, sleeping, sitting at sentinel posts, drinking and fishing in ponds. Pairs of cats fought, played or sat with each other. Twenty hunting events were captured on camera (three in sampling period 1; 10 in period 2; seven in period 3) and included: one cat with a caught bird, another hunting birds, one cat hunting a cricket, another with a caught rodent, and one cat repeatedly hunting and catching skinks (at least one *Morethia* sp.) amongst pot plants. One cat stalked native quenda (a species of bandicoot, *Isoodon fuscivente*r) on four evenings, with one event interrupted by the triggered deterrent (see Supp. Fig. A3 – A.15 for records of behaviour).

Table 3
Basic demographics of cats active at garden sites during trials of ultrasonic deterrents in Perth, Western Australia. See Supp. Table A3 for more details.

Garden Site	Total Cats	Females	Males	Unknown Sex	Reproductive	Owned	Resident
1	4	1	2	1	1	2	3
2	6	1	3	2	3	2	–
3	5	1	–	4	–	5	2
4	4	–	2	2	1	3	2
5	4	1	2	1	–	1	–
6	5	1	4	–	2	5	3
7	7	1	2	4	2	2	2
8	6	2	2	2	1	2	2
9	5	2	–	3	–	2	2
10	2	–	–	2	–	–	–
11	2	–	1	1	1	–	–
12	3	–	1	2	1	3	1
13	4	1	2	1	3	1	1
14	4	1	1	2	1	4	2
15	5	1	3	1	3	4	3
16	3	–	2	1	1	1	1
17	9	2	1	6	–	2	2
18	–	–	–	–	–	–	–
Total	78	15	28	35	20	41	26
%	100.0	19.20	35.90	44.9	25.6	52.6	33.3

Table 4
Results of mixed-effect generalised linear model quantifying cat activity (number events per day) in 17 suburban gardens (Perth, Western Australia) in relation to ultrasonic deterrent status (On, Off), deterrent model (CatStop, OnGuard), transience (Resident, Peripheral) and cat attributes (Sex, Owned).

Predictor	Term	S.E.	z value	p value
Intercept	- 0.28	0.30	- 0.95	0.34
Sex: Male (Reference category female)	0.54	0.27	2.03	0.04
Sex: Unknown (Reference category female)	0.34	0.28	1.22	0.22
Owned: Yes (Reference category unknown)	0.47	0.21	2.24	0.03
Transience: Resident (Reference category peripheral)	2.03	0.23	8.99	<0.001
Deterrent: On-Guard (Reference category CatStop)	- 0.03	0.19	- 0.14	0.89
Period 2: On (Reference category Period 1 Off)	- 0.17	0.15	- 1.12	0.26
Period 3: Off (Reference category Period 1 Off)	0.05	0.14	0.38	0.71
Period 2 * Transience: Resident	- 0.59	0.18	- 3.32	0.001
Period 3 * Transience: Resident	- 1.04	0.17	- 5.98	<0.001

3.2.2. Responses to ultrasonic devices

Cameras captured the reactions of 32 cats who encountered active ultrasonic deterrents. Reactions to the devices varied with some cats freezing then moving/running away, others searched for/approached the device, and one cat known to be congenitally deaf did not detect or react to the deterrent. Overall, the ultrasonic deterrents reduced the frequency of incursions into gardens by resident cats by 46%, with the duration of incursions reduced by 78%.

The top model contained additive terms and one two-way interaction, demonstrating large changes in cat activity across periods and transience (Resident, Peripheral), and weaker effects of sex and ownership (Table 4). Resident cat activity was higher than activity of peripherals (9.3 vs. 1.7 events/day; $z = 8.99$, $p < 0.001$). Cat activity declined markedly from period 1 (baseline) to period 2 for resident cats but not peripheral cats (15.1 vs. 7.1 events/day; $z = -3.32$, $p = 0.001$), and remained depressed in period 3 for resident cats but not peripheral cats (device switched off again, $z = -5.98$, $p < 0.001$), (Fig. 6, Table 4). Resident cats declined in activity to such an extent that only nine of the original 26 resident cats (34.6%) remained the most active animals at seven (of 13) gardens. Cats confirmed as owned generated three times more activity than cats of unknown ownership status ($z = 2.2$, $p = 0.03$, Fig. 7), which likely reflects proximity of their residences to trial gardens. Activity of ultrasonic deterrent models did not differ in effectiveness ($z = 0.14$, $p = 0.89$; Table 4). Males were slightly more active than females over the experiment (5.5 vs. 4.2 events/day; $z = 2.0$, $p = 0.04$).

3.2.3. Responses of non-target fauna

Cameras detected a range of fauna other than cats during the trials, including numerous birds, the introduced black rat (*Rattus rattus*), red foxes, domestic dogs, bats (sp. unknown), and two native marsupials– the quenda and brushtail possum (*Trichosurus vulpecula*). Quenda, possums and foxes were detected while ultrasonic devices were switched on, including one instance of quenda copulating in front of the deterrent (Suppl. Fig. A.16). While data were too infrequent to attempt statistical analysis, only foxes reacted with fright when active deterrents were triggered (Supp. Fig. A.17, A.18). Swooping bats were occasionally captured on camera but whether they were present naturally or attracted to active cameras and/or deterrents is unknown (Supp. Fig. A.19).

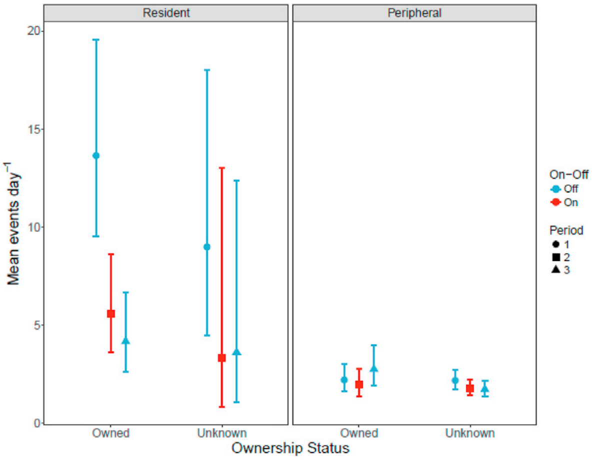

Fig. 6. Mean number of trap events for 41 owned cats and 37 cats with unknown ownership status, in three trapping periods. Error bars are 95.0% confidence limits. They are asymmetrical following back-transformation from a Poisson distribution.

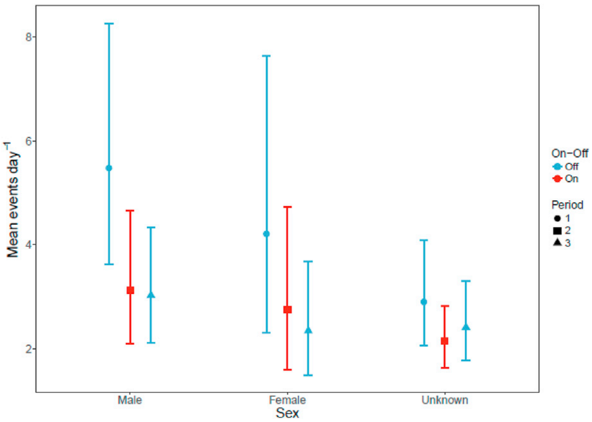

Fig. 7. Mean number of trap events for 29 male, 15 female and 34 cats of unknown sex, in three sampling periods. Error bars are 95.0% confidence limits. They are asymmetrical following back-transformation from a Poisson distribution.

4. Discussion

4.1. Device effectiveness

Several commercially available ultrasonic deterrents are marketed as being effective against cats; however, only two are known to have been independently trialled for efficacy: the Pestaway Champ© (Mills et al., 2000) and the Catwatch© (Nelson et al., 2006). Based on arena trials, Mills et al. (2000) concluded that cats could detect the Pestaway Champ but did not find it aversive. Nelson et al. (2006) reported reductions in both the probability of incursions (32%) and the duration of incursions (38%) in U.K. garden settings, relying on reports from householders on their perception of cat activity during three 30 min/week defined periods. In our study the CS was detected by all cats in arena trials and increased anxious and fearful responses relative to other behaviours, which suggested potential for deterring cat activity in the field. In our field trials, continuous monitoring using camera data confirmed that the CS and the OG both reduced the frequency of incursions (46%) into gardens by resident cats, and this reduction persisted when the devices were switched off. The duration of incursions was reduced by 78%. Based on these results, ultrasonic technology could assist suburban residents wishing to humanely reduce incursions onto their properties by unwanted nuisance cats.

Careful placement of devices at foci of cat activity, as recommended by Nelson et al. (2006), may have been important in the success of our trials. To reduce habituation, it may be valuable to shift the location of devices periodically, so that cats are surprised.

An important caveat to the effectiveness of deterrents is that owners of gardens in suburbs with high cat densities may successfully deter nuisance cats only to have them replaced by others. When multiple cats are forced into proximity, desirable resources such as fish ponds, are typically 'time-shared', with cats accessing the resource at different times of the day and night to prevent physical encounters (Bernstein and Strack, 1996; Recio and Seddon, 2013). To retain access to resources and communicate when they are present, cats must regularly patrol, and scent-mark areas of use (Feldman, 1994). In the absence of resident cats, peripheral or new cats may commandeer the resource or access period. In 13 trial gardens, ultrasonic deterrents reduced activity duration of 22 of the 26 resident cats (84.6%). When deterrents were deactivated once more, only nine resident cats (34.6%) remained the most active cats at seven gardens. This shift in activity patterns in response to deterrents hints at the flexibility of cat home ranges when densities are high (Hall et al., 2016a). Therefore, to prevent substitution of one nuisance cat for another, we recommend ultrasonic deterrents be coupled with other preventive measures (e.g. netting over ponds, improved fencing, DCMB, 2016).

4.2. Limitations of the study

It was noted during field trials that some deterrent devices were not entirely waterproof and that towards the end of sampling period 2 several devices were making whining sounds audible to people. Whilst the deterrent results are significant, improvements to model design or technology could improve confidence in performance. Costs of replacing or maintaining deterrents must be borne by the property owner.

Our short study documented reduced cat activity, which is not the same as removing cats from the landscape. Furthermore, within the scope of our study we did not test the possibility of habituation. Our evidence from Period 3 (deterrents turned off) strongly suggests resident cats retain their altered behaviour for at least two weeks. More work on longer term dynamics would be warranted using telemetry or similar individual-based study.

4.3. Conservation implications

Suburban gardens harbour a wide range of wildlife in Perth (Kennedy et al., 2018) and across Australia, including endangered species (Ives et al., 2016). During garden trials, cameras captured six cats hunting fauna on 20 separate occasions, including 10 when deterrents were active. Although one cat paused hunting when it encountered the active deterrent, this was not always the case. Therefore ultrasonic deterrents may not stop hunting behaviour when it is underway, although by reducing incursions they may reduce the frequency of encounters between cats and prey.

The observations of a cat regularly hunting lizards are consistent with cat predation affecting lizard populations in suburban Perth (Bamford and Calver, 2012), while observations of cats stalking quenda are consistent with established reports of pet cats killing quenda (Calver et al., 2007; Hall et al., 2015). Some owners may have been concerned about their cat's hunting, because nine cats wore collars with bells (11.5% of all cats). While there is experimental evidence that bells do reduce prey capture rates (Calver et al., 2007; Ruxton et al., 2002), they do not eliminate hunting altogether or reduce sub-lethal effects (Bonnington et al., 2013). Using ultrasonic deterrents may dissuade some cats from hunting in gardens but as long as pet and stray cats roam freely, hunting pressure will be exerted on fauna.

The possible startling of desirable garden fauna is a concern when using ultrasonic deterrents, especially if the reason for deployment is to protect and encourage fauna normally harassed by cats. Ultrasonic deterrents have no discernible effects on the behaviour of three macropod species in the field (Bender, 2003; Muirhead et al., 2006), but published data on other marsupials is sparse. Although we found no evidence that birds, quenda or possums were disturbed by the devices in our trials, our data are slight and individual property owners would need to make their own decisions. Some bat species are likely to be sensitive to the sound emitted by triggered ultrasonic devices (Fullard et al., 1991), but whether or not this disrupted normal behaviour or otherwise posed a threat was not evaluated.

4.4. Characteristics of roaming nuisance cats

More than half of the 78 detected cats were confirmed as pets belonging to neighbours near trial gardens. The physical condition of most cats was healthy or heavy, regardless of ownership status (100.0% of owned cats, and 94.6% of cats of unknown ownership status), suggesting that cats had access to anthropogenic resources, and/or were hunting enough wildlife to thrive. The prevalence of confirmed pet cats (52.6%) amongst nuisance animals implies that cat owners are complicit in nuisance activity.

Nuisance complaints about cat activity are frequently associated with cat reproduction (e.g. aggression, increased invasion onto private properties, and injuries to cats, Gunther et al., 2011). Desexing reduces fighting, urine-spraying and desire to roam in search of mating opportunities (Hart and Barrett, 1973), so high community desexing rates may reduce nuisance complaints. However, despite numerous estimates of >90.0% desexing rates in Australian pet cat populations (96.3% of $n = 4314$, Roetman et al., 2017; 96.5% of $n = 199$, Toribio et al., 2008), at least one female and 19 of the male cats in the garden trials were sexually entire (25.6%). Johnson and Calver (2014) reported that although $\approx$ 94.7% of 661 cats in their study aged two or more years were desexed, less than half the cats aged under two years were desexed ($\approx$42.2% of $n = 239$). Thus, our observations may suggest that the nuisance cats are younger. Hall et al. (2016b) reported desexing rates > 90.0% in pet cats from cities in Australia, New Zealand, the U.S.A., the U.K. and Japan, so the high desexing rates in those countries may also be no assurance that sexually entire animals, especially younger ones, are not creating a nuisance. Encouraging cat owners to desex cats before sexual maturity helps minimise the unwanted cat population (prepubertal desexing $\leq$ 4 months of age, Joyce and Yates, 2011) and, if there is high community uptake, prepubertal desexing may reduce nuisance complaints from both cat and non-cat owners.

In the absence of enforcement, cat ownership legislation is unlikely to solve nuisance issues caused by roaming cats. Western Australia's Cat Act (2011) mandates the desexing and microchipping of pet cats and their registration with municipal councils by the age of six months. Cats must also wear collars with registration tags and owner contact details. The prevalence of entire animals in our samples (25.6%) and the fact that only 33.3% of cats wore collars, none of which exhibited a registration tag, and only nine of which had an ID tag (11.5%), is evidence of non-compliance with these requirements. Elsewhere in Australia, Pert (2001) and Scheele (2001) have noted low compliance with registration requirements. This is despite solid support for cat legislation in Australia, including by > 60.0% of cat owners and >80.0% of non-owners (Grayson and Calver, 2004; Hall et al., 2016b; Lilith et al., 2006). Elsewhere in the world support for legislation is more modest (e.g. only 25.0% of U.K. cat owners see a need for legislation, Hall et al., 2016b). Given that compliance is a problem even when there is community support for legislation, legislation may not be highly effective in reducing the problems caused by roaming cats unless it is accompanied by rigorous enforcement.

In Tasmania, Australia, McLeod et al. (2015) found that cat owners valued their own convenience and the welfare of their pets above any perceived problems caused by their cats' roaming. Therefore, community education to reduce cat nuisance might profitably focus on hazards to roaming cats such as road accident trauma, fighting, exposure to disease risks and human persecution (Loyd et al., 2013b; McLeod et al., 2017). However, even these approaches are unlikely to influence the 57.0% of owners McLeod et al. (2015) found either believed it would be cruel to restrict their cats' roaming, or claimed emotional detachment from their cats, lack of interest, or general indifference as reasons for not restricting their cats' roaming. Additional public education is needed here. Furthermore, the hard work of municipal authorities, cat charities, and responsible law-abiding cat owners will be undermined if populations of semi-feral cats persist in suburbs. Therefore, regulation of pet cats should be accompanied by active removal and rehoming of semi-feral cats from suburbs, to prevent fighting, spread of disease, uncontrolled breeding and the roaming behaviour driving nuisance activities.

In conclusion, while there are currently no perfect solutions for the issues caused by roaming cats, ultrasonic deterrents offer a cost-effective, humane option for landholders wishing to reduce incursions by unwanted cats onto their properties. Ultrasonic deterrents will not prevent all incursions, but they should reduce their frequency and duration. If deterrents are regularly moved around gardens and coupled with other preventative measures (e.g. netting over ponds, improved fencing) then nuisance activity can be curtailed. Although our data apply only to domestic gardens, ultrasonic devices may deter cats from other settings such as parks and public gardens, as well as non-urban settings such as breeding colonies for birds or offer added security at gates of predator-exclusion fences.

Ethics statement

Part 1. Cat behaviour trials were carried out with permission of Murdoch University Animal Ethics Committee (permit number: R2679/14) and the Cat Haven shelter.

Part 2. Domestic garden trials carried out with permission of Murdoch University Human Ethics Committee (permit number: 2016/066), and the 18 garden owners who took part in trials.

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Declaration of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2018.e00444.

References

ABS, 2016a. Australian Bureau of Statistics. 3218.0 regional population, Australia 2016. Available online: http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3218.0. (Accessed 12 October 2017).

ABS, 2016b. Australian Beureau of Statistics. Statistics of Greater Perth, western Australia. Available online: http://stat.abs.gov.au/itt/r.jsp?RegionSummary&region=5GPER&dataset=ABS_REGIONAL_ASGS2016&geoconcept=ASGS_2016&measure=MEASURE&datasetASGS=ABS_REGIONAL_ASGS2016&datasetLGA=ABS_REGIONAL_LGA2016&regionLGA=LGA_2016&regionASGS=ASGS_2016. (Accessed 12 October 2017).

Aguilar, G.D., Farnworth, M.J., 2013. Distribution characteristics of unmanaged cat colonies over a 20 year period in Auckland, New Zealand. Appl. Geogr. 37, 160–167. https://dx.doi.org/10.1016/j.apgeog.2012.11.009.

Alonso, J.M., Stein, M., Chamorro, M.C., Bojanich, M.V., 2001. Contamination of soils with eggs of Toxocara in a subtropical city in Argentina. J. Helminthol. 75 (2), 165–168. https://dx.doi.org/10.1079/JOH200146.

AMA, 2016. Pet ownership in Australia 2016. Animal Medicines Australia, new south Wales, Australia. Available online: www.animalmedicinesaustralia.org.au. (Accessed 17 October 2017).

APPA, 2015-2016. National Pet Owners Survey. American Pet Products Association, U.S.A. Available online: www.americanpetproducts.org. (Accessed 17 September 2017).

Baker, P.J., Soulsbury, C.D., Iossa, G., Harris, S., 2010. Domestic Cat (*Felis catus*) and Domestic Dog (*Canis familiaris*). In: Gehrt, S.D., Riley, S.P.D., Cypher, B.L. (Eds.), Urban Carnivores: Ecology, Conflict, and Conservation. John Hopkins University Press, Baltimore, U.S.A., pp. 157–171

Bamford, M.J., Calver, M.C., 2012. Cat predation and suburban lizards: A 22 year study at a suburban Australian property. Open Conserv. Biol. J. 6, 25–29. https://doi.org/10.2174/1874839201206010025.

Bates, D., Mäechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Software 67 (1), 1–48. https://dx.doi.org/10.18637/jss.v067.i01.

Beckerman, A.P., Boots, M., Gaston, K.J., 2007. Urban bird declines and the fear of cats. Anim. Conserv. 10 (3), 320–325. https://doi.org/10.1111/j.1469-1795.2007.00115.x.

Bender, H., 2003. Deterrence of kangaroos from agricultural areas using ultrasonic frequencies: Efficacy of a commercial device. Wildl. Soc. Bull. 31 (4), 1037–1046.

Bernstein, P.L., Strack, M., 1996. A game of cat and house: Spatial patterns and behavior of 14 domestic cats (*Felis catus*) in the home. Anthrozoös 9 (1), 25–39. https://dx.doi.org/10.2752/089279396787001572.

Bonnington, C., Gaston, K.J., Evans, K.L., 2013. Fearing the feline: Domestic cats reduce avian fecundity through trait-mediated indirect effects that increase nest predation by other species. J. Appl. Ecol. 50, 15–24. https://doi.org/10.1111/1365-2664.12025.

Bradshaw, J.W.S., Casey, R.A., Brown, S.L., 2012. The Cat-Human Relationship. In: The Behaviour of the Domestic Cat, second ed. CABI Publishers, Bristol, U.K., pp. 161–174

Calver, M., Thomas, S., Bradley, S., McCutcheon, H., 2007. Reducing the rate of predation on wildlife by pet cats: The efficacy and practicability of collar-mounted pounce protectors. Biol. Conserv. 137, 341–348. https://dx.doi.org/10.1016/j.biocon.2007.02.015.

Calver, M.C., Grayson, J., Lilith, M., Dickman, C.R., 2011. Applying the precautionary principle to the issue of impacts by pet cats on urban wildlife. Biol. Conserv. 144 (6), 1895–1901. https://dx.doi.org/10.1016/j.biocon.2011.04.015.

Coates, T.D., Wright, C.J., 2003. Predation of southern brown bandicoots *Isoodon obesulus* by the European red fox *Vulpes vulpes* in south-east Victoria. Aust. Mammal. 25 (1), 107–110. https://doi.org/10.1071/AM03107.

Cox, D.T.C., Gaston, K.J., 2016. Urban bird feeding: Connecting people with nature. PLoS One 11 (7) e0158717. https://dx.doi.org/10.1371/journal.pone.0158717.

Dabritz, H.A., Conrad, P.A., 2010. Cats and Toxoplasma: Implications for public health. Zoonoses and Public Health 57 (1), 34–52. https://doi.org/10.1111/j.1863-2378.2009.01273.x.

Daniels, G.D., Kirkpatrick, J.B., 2006. Does variation in garden characteristics influence the conservation of birds in suburbia? Biol. Conserv. 133 (3), 326–335. https://dx.doi.org/10.1016/j.biocon.2006.06.011.

Dauphiné, N., Cooper, R.J., 2009. Impacts of free-ranging domestic cats (*Felis catus*) on birds in the United States: A review of recent research with conservation and management recommendations. In: Proceedings 4th International Partners in Flight Conference, pp. 205–219.

DCMB, 2016. Good Cats Play at Home. Dog and Cat Management Board, Adelaide, Australia. Available online: www.dogandcatboard.com.au. (Accessed 20 November 2017).

FEDIAF, 2014. Facts and Figures 2014. European Pet Food Industry Federation, Brussels, Belgium. Available online: www.fediaf.org. (Accessed 18 November 2017).

Feldman, H.N., 1994. Methods of scent marking in the domestic cat. Can. J. Zool. 72 (6), 1093–1099. https://dx.doi.org/10.1139/z94-147.

Fernández-Juricic, E., Jokimäki, J., 2001. A habitat island approach to conserving birds in urban landscapes: Case studies from southern and northern Europe. Biodivers. Conserv. 10 (12), 2023–2043. https://doi.org/10.1023/A:1013133308987.

Finkler, H., Hatna, E., Terkel, J., 2011a. The influence of neighbourhood socio-demographic factors on densities of free-roaming cat populations in an urban ecosystem in Israel. Journal of Wildlife Research 38 (3), 235–243. https://dx.doi.org/10.1071/WR10215.

Finkler, H., Gunther, I., Terkel, J., 2011b. Behavioral differences between urban feeding groups of neutered and sexually intact free-roaming cats following a trap-neuter-return procedure. J. Am. Vet. Med. Assoc. 238 (9), 1141–1149. https://dx.doi.org/10.2460/javma.238.9.1141.

Fullard, J.H., Koehler, C., Surlykke, A., McKenzie, N.L., 1991. Echolocation ecology and morphology of insectivorous bats (Chiroptera) in south-western Australia. Aust. J. Zool. 39 (4), 427–438. https://doi.org/10.1071/ZO9910427.

Gehrt, S.D., Riley, S.P.D., 2010. Coyotes (*Canis latrans*). In: Gehrt, S.D., Riley, S.P.D., Cypher, B.L. (Eds.), Urban Carnivores: Ecology, Conflict, and Conservation. John Hopkins University Press, Baltimore, U.S.A., pp. 79–96

Grayson, J., Calver, M., 2004. Regulation of domestic cat ownership to protect urban wildlife: A justification based on the precautionary principle. In: Lunney, D., Burgin, S. (Eds.), Urban Wildlife: More than Meets the Eye. Royal Zoological Society of New South Wales, Mosman, Australia, pp. 169–178.

Gunther, I., Finkler, H., Terkel, J., 2011. Demographic differences between urban feeding groups of neutered and sexually intact free-roaming cats following a trap-neuter-return procedure. J. Am. Vet. Med. Assoc. 238 (9), 1134–1140. https://dx.doi.org/10.2460/javma.238.9.1134.

Hall, C.M., Fontaine, J.B., Bryant, K.A., Calver, M.C., 2015. Assessing the effectiveness of the Birdsbesafe® anti-predation collar cover in reducing predation on wildlife by pet cats in Western Australia. Appl. Anim. Behav. Sci. 173, 40–51. https://dx.doi.org/10.1016/j.applanim.2015.01.004.

Hall, C.M., Bryant, K.A., Haskard, K., Major, T., Bruce, S.J., Calver, M.C., 2016a. Factors determining the home ranges of pet cats: A meta-analysis. Biol. Conserv. 203, 313–320. https://doi.org/10.1016/j.biocon.2016.09.029.

Hall, C.M., Adams, N.A., Bradley, J.S., Bryant, K.A., Davis, A.A., Dickman, C.R., Fujita, T., Kobayashi, S., Lepczyk, C.A., McBride, E.A., Pollock, K.H., Styles, I.M., van Heezik, Y., Wang, F., Calver, M.C., 2016b. Community attitudes and practices of urban residents regarding predation by pet cats on wildlife: An international comparison. PLoS One 11 (4) e0151962. https://doi.org/10.1371/journal.pone.0151962.

Hart, B.L., Barrett, R.E., 1973. Effects of castration on fighting, roaming, and urine spraying in adult male cats. J. Am. Vet. Med. Assoc. 163 (3), 290–292.

Heffner, R.S., Heffner, H.E., 1985. Hearing range of the domestic cat. Hear. Res. 19 (1), 85–88. https://dx.doi.org/10.1016/0378-5955(85)90100-5.

Hellard, E., Fouchet, D., Santin-Janin, H., Tarin, B., Badol, V., Coupier, C., Leblanc, G., Poulet, H., Pontier, D., 2011. When cats' ways of life interact with their viruses: A study in 15 natural populations of owned and unowned cats (*Felis silvestris catus*). Prev. Vet. Med. 101 (3–4), 250–264. https://dx.doi.org/10.1016/j.prevetmed.2011.04.020.

Ives, C.D., Lentini, P.E., Threlfall, C.G., Ikin, K., Shanahan, D.F., Garrard, G.E., Bekessy, S.A., Fuller, R.A., Mumaw, L., Rayner, L., Rowe, R., Valentine, L.E., Kendal, D., 2016. Cities are hotspots for threatened species. Global Ecol. Biogeogr. 25, 117–126. https://doi.org/10.1111/geb.12404.

Johnson, J., Calver, M.C., 2014. Prevalence of desexed cats in relation to age in a convenience sample of Western Australian cats. Aust. Vet. J. 92 (6), 226–227. https://doi.org/10.1111/avj.12182.
Joyce, A., Yates, D., 2011. Help stop teenage pregnancy! Early-age neutering in cats. J. Feline Med. Surg. 13, 3–10. https://doi.org/10.1016/j.jfms.2010.11.005.
Kennedy, P.L., Fontaine, J.B., Hobbs, R.J., Johnson, T.N., Boyle, R., Lueders, A.S., 2018. Do novel ecosystems provide habitat value for wildlife? Revisiting the physiognomy vs. floristics debate. Ecosphere 9 (3) e02172. https://doi.org/10.1002/ecs2.2172.
Ley, J.M., Seksel, K., 2012. Chapter 10 - Normal Behavior of Cats. In: Little, S.E. (Ed.), The Cat: Clinical Medicine and Management. W.B. Saunders, Saint Louis, U.S.A., pp. 191–197. https://doi.org/10.1016/B978-1-4377-0660-4.00010-7
Liberg, O., Sandell, M., Pontier, D., Natoli, E., 2000. Density, Spatial Organisation and Reproductive Tactics in the Domestic Cat and Other Felids. In: Turner, D. C., Bateson, P. (Eds.), The Domestic Cat: the Biology of its Behaviour, second ed. Cambridge University Press Ltd, Cambridge, U.K., pp. 119–147
Lilith, M., Calver, M., Styles, I., Garkaklis, M.J., 2006. Protecting wildlife from predation by owned domestic cats: Application of a precautionary approach to the acceptability of proposed cat regulations. Austral Ecol. 31 (2), 176–189. https://doi.org/10.1111/j.1442-9993.2006.01582.x.
Lohr, C.A., Cox, L.J., Lepczyk, C.A., 2013. Costs and Benefits of Trap-Neuter-Release and Euthanasia for Removal of Urban Cats in Oahu, Hawaii. Conserv. Biol. 27 (1), 64–73. https://doi.org/10.1111/j.1523-1739.2012.01935.x.
Lohr, C.A., Lepczyk, C.A., 2014. Desires and management preferences of stakeholders regarding feral cats in the hawaiian Islands. Conserv. Biol. 28 (2), 392–403. https://doi.org/10.1111/cobi.12201.
Lohr, C.A., Lepczyk, C.A., Cox, L.J., 2014. Identifying people's most preferred management technique for feral cats in Hawaii. Human-Wildlife Interactions 8 (1), 56–66.
Longcore, T., Rich, C., Sullivan, L.M., 2009. Critical assessment of claims regarding management of feral cats by trap-neuter-return. Conserv. Biol. 23 (4), 887–894. https://doi.org/10.1111/j.1523-1739.2009.01174.x.
Loss, S.R., Will, T., Marra, P.P., 2013. The impact of free-ranging domestic cats on wildlife of the United States. Nat. Commun. 4, 1–7. https://dx.doi.org/10.1038/ncomms2380.
Loyd, K.A.T., Hernandez, S.M., Carroll, J.P., Abernathy, K.J., Marshall, G.J., 2013a. Quantifying free-roaming domestic cat predation using animal-borne video cameras. Biol. Conserv. 160, 183–189. https://dx.doi.org/10.1016/j.biocon.2013.01.008.
Loyd, K.A.T., Hernandez, S.M., Abernathy, K.J., Shock, B.C., Marshall, G.J., 2013b. Risk behaviours exhibited by free-roaming cats in a suburban US town. Vet. Rec. 173 (12), 295–300. https://doi.org/10.1136/vr.101222.
Mameno, K., Kubo, T., Suzuki, M., 2017. Social challenges of spatial planning for outdoor cat management in Amami Oshima Island, Japan. Global Ecology and Conservation 10, 184–193. https://dx.doi.org/10.1016/j.gecco.2017.03.007.
Marra, P.P., Santella, C., 2016. Cat Wars: the Devastating Consequences of a Cuddly Killer. Princeton University Press, Princeton, U.S.A., p. 212
McLeod, L.J., Hine, D.W., Bengsen, A.J., 2015. Born to roam? Surveying cat owners in Tasmania, Australia, to identify the drivers and barriers to cat containment. Prev. Vet. Med. 122 (3), 339–344. https://dx.doi.org/10.1016/j.prevetmed.2015.11.007.
McLeod, L.J., Hine, D.W., Bengsen, A.J., 2017. Assessing the impact of different persuasive messages on the intentions and behaviour of cat owners: A randomised control trial. Prev. Vet. Med. 146, 136–142. https://dx.doi.org/10.1016/j.prevetmed.2017.08.005.
McRuer, D.L., Gray, L.C., Horne, L., Clark, E.E., 2017. Free-roaming cat interactions with wildlife admitted to a wildlife hospital. J. Wildl. Manag. 81 (1), 163–173. https://doi.org/10.1002/jwmg.21181.
Mills, D.S., Bailey, S.L., Thurstans, R.E., 2000. Evaluation of the welfare implications and efficacy of an ultrasonic 'deterrent' for cats. Vet. Rec. 147 (24), 678–680. https://doi.org/10.1136/vr.147.24.678.
Mirmovitch, V., 1995. Spatial organisation of urban feral cats (*Felis catus*) in Jerusalem. Journal of Wildlife Research 22 (3), 299–310. https://doi.org/10.1071/WR9950299.
Muirhead, S., Blache, D., Wykes, B., Bencini, R., 2006. Roo-Guard® sound emitters are not effective at deterring tammar wallabies (*Macropus eugenii*) from a source of food. Journal of Wildlife Research 33 (2), 131–136. https://doi.org/10.1071/WR04032.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858. https://doi.org/10.1038/35002501.
Natoli, E., Ferrari, M., Bolletti, E., Pontier, D., 1999. Relationships between cat lovers and feral cats in Rome. Anthrozoös 12 (1), 16–23. https://doi.org/10.2752/089279399787000408.
Natoli, E., Say, L., Cafazzo, S., Bonanni, R., Schmid, M., Pontier, D., 2005. Bold attitude makes male urban feral domestic cats more vulnerable to Feline Immunodeficiency Virus. Neurosci. Biobehav. Rev. 29 (1), 151–157. https://doi.org/10.1016/j.neubiorev.2004.06.011.
Nelson, S.H., Evans, A.D., Bradbury, R.B., 2006. The efficacy of an ultrasonic cat deterrent. Appl. Anim. Behav. Sci. 96 (1–2), 83–91. https://doi.org/10.1016/j.applanim.2005.05.005.
Nielsen, A.B., van den Bosch, M., Maruthaveeran, S., van den Bosch, C.K., 2014. Species richness in urban parks and its drivers: A review of empirical evidence. Urban Ecosyst. 17 (1), 305–327. https://doi.org/10.1007/s11252-013-0316-1.
NZCAC, 2016. Companion Animals in New Zealand 2016. New Zealand Companion Animal Council Inc., Auckland, New Zealand. Available online: www.nzcac.org.nz. (Accessed 10 October 2017).
Pert, T., 2001. NSW Companion Animals Act 1998. Funding- is it adequate for animal management?. In: Proceedings 10th National Conference on Urban Animal Management in Australia, pp. 49–52. Melbourne, Australia.
Peterson, M.N., Hartis, B., Rodriguez, S., Green, M., Lepczyk, C.A., 2012. Opinions from the front lines of cat colony management conflict. PLoS One 7 (9) e44616. https://dx.doi.org/10.1371/journal.pone.0044616.
Portfors, C.V., 2007. Types and functions of ultrasonic vocalizations in laboratory rats and mice. JAALAS 46 (1), 28–34.
R Core Team, 2018. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available online: www.R-project.org/. (Accessed 2 March 2018).
Recio, M.R., Seddon, P.J., 2013. Understanding determinants of home range behaviour of feral cats as introduced apex predators in insular ecosystems: A spatial approach. Behav. Ecol. Sociobiol. 67 (12), 1971–1981. https://doi.org/10.1007/s00265-013-1605-7.
Rix, M.G., Edwards, D.L., Byrne, M., Harvey, M.S., Joseph, L., Roberts, J.D., 2015. Biogeography and speciation of terrestrial fauna in the south-western Australian biodiversity hotspot. Biol. Rev. 90 (3), 762–793. https://doi.org/10.1111/brv.12132.
Robinson, R., 1991. Genetics for Cat Breeders. Reed Educational and Professional Publishing Ltd., Oxford, U.K., p. 234
Rochlitz, I., 2003a. Study of factors that may predispose domestic cats to road traffic accidents: Part 1. Vet. Rec. 153, 549–553. https://doi.org/10.1136/vr.153.18.549.
Rochlitz, I., 2003b. Study of factors that may predispose domestic cats to road traffic accidents: Part 2. Vet. Rec. 153, 585–588. https://doi.org/10.1136/vr.153.19.585.
Rodan, I., 2012. Chapter 1 - Understanding the Cat and Feline-Friendly Handling. In: Little, S.E. (Ed.), The Cat: Clinical Medicine and Management. W.B. Saunders, Saint Louis, U.S.A., pp. 2–19. https://dx.doi.org/10.1016/B978-1-4377-0660-4.00001-6
Roetman, P., Tindle, H., Litchfield, C., Chiera, B., Quinton, G., Kikillus, H., Bruce, D., Kays, R., 2017. Cat Tracker South Australia: Understanding Pet Cats through Citizen Science. Discovery Circle Initiative. University of South Australia, Adelaide, Australia, p. 80. https://doi.org/10.4226/78/5892ce70b245a.
Ruxton, G.D., Thomas, S., Wright, J.W., 2002. Bells reduce predation of wildlife by domestic cats (*Felis catus*). J. Zool.: Proc. Zool. Soc. Lond. 256 (1), 81–83. https://doi.org/10.1017/S0952836902000109.
Sandøe, P., Nørspang, A.P., Forkman, B., Bjørnvad, C.R., Kondrup, S.V., Lund, T.B., 2017. The burden of domestication: A representative study of welfare in privately owned cats in Denmark. Anim. Welf. 26 (1), 1–10. https://doi.org/10.7120/09627286.26.1.001.
Scheele, M., 2001. Cat pounds - Manningham City Council perspective. In: Proceedings 10th National Conference on Urban Animal Management in Australia, pp. 69–71. Melbourne, Australia.

Spehar, D.D., Wolf, P.J., 2018. A case study in citizen science: The effectiveness of a trap-neuter-return program in a chicago neighborhood. Animals 8 (1). https://doi.org/10.3390/ani8010014.
Taetzsch, S.J., Bertke, A.S., Gruszynski, K.R., 2018. Zoonotic disease transmission associated with feral cats in a metropolitan area: A geospatial analysis. Zoonoses and Public Health 1–8. https://doi.org/10.1111/zph.12449.
Tan, K., Rand, J., Morton, J., 2017. Trap-Neuter-Return activities in urban stray cat colonies in Australia. Animals 7 (6), 46–67. https://doi.org/10.3390/ani7060046.
Toribio, J.A.L., Norris, J.M., White, J.D., Dhand, N.K., Hamilton, S.A., Malik, R., 2008. Demographics and husbandry of pet cats living in Sydney, Australia: Results of cross-sectional survey of pet ownership. J. Feline Med. Surg. 11 (6), 449–461. https://doi.org/10.1016/j.jfms.2008.06.010.
Toukhsati, S.R., Phillips, C.J.C., Podberscek, A.L., Coleman, G.J., 2012. Semi-ownership and sterilisation of cats and dogs in Thailand. Animals 2 (4), 611–627. https://dx.doi.org/10.3390/ani2040611.
Uetake, K., Yamada, S., Yano, M., Tanaka, T., 2014. A survey of attitudes of local citizens of a residential area toward urban stray cats in Japan. J. Appl. Anim. Welfare Sci. 17 (2), 172–177. https://dx.doi.org/10.1080/10888705.2013.798558.
van den Bos, R., 1998. Post-conflict stress-response in confined group-living cats (*Felis silvestris catus*). Appl. Anim. Behav. Sci. 59 (4), 323–330. https://doi.org/10.1016/S0168-1591(98)00147-6.
Vinke, C.M., Godijn, L.M., van der Leij, W.J.R., 2014. Will a hiding box provide stress reduction for shelter cats? Appl. Anim. Behav. Sci. 160, 86–93. https://doi.org/10.1016/j.applanim.2014.09.002.
Vnuk, D., Capak, H., Gusak, V., Maticic, D., Popovic, M., Bottegaro, N.B., 2016. Metal projectile injuries in cats: Review of 65 cases (2012-2014). J. Feline Med. Surg. 18 (8), 626–631. https://doi.org/10.1177/1098612X15590869.
Western Australian Cat Act, 2011. Government of Western Australia, Perth, Australia. Available online: www.dlgc.wa.gov.au/AdviceSupport/Pages/Cats-and-dogs.aspx. (Accessed 11 October 2017).
Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis, second ed. Springer Nature, Switzerland.
Xavier, F.G., Kogika, M.M., de Souza Spinosa, H., 2002. Common causes of poisoning in dogs and cats in a Brazilian veterinary teaching hospital from 1998 to 2000. Vet. Hum. Toxicol. 44 (2), 115–116.
Yamaguchi, N., MacDonald, D.W., Passanisi, W.C., Harbour, D.A., Hopper, C.D., 1996. Parasite prevalence in free-ranging farm cats, *Felis silvestris catus*. Epidemiol. Infect. 116 (2), 217–223. https://dx.doi.org/10.1017/S0950268800052468.
Zasloff, L.R., Hart, L.A., 1998. Attitudes and care practices of cat caretakers in Hawaii. Anthrozoös 11 (4), 242–248. https://doi.org/10.2752/089279398787000599.
Zito, S., Vankan, D., Bennett, P., Paterson, M., Phillips, C., 2015. Cat ownership perception and caretaking explored in an internet survey of people associated with cats. PLoS One 10 (7) e0133293. https://dx.doi.org/10.1371/journal.pone.0133293.