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Do collar-mounted predation deterrents restrict wandering in pet domestic cats?

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Highlights

- Roaming behaviour was unchanged when cats wore predation deterrents.
- Deterrent effectiveness stems from interference with hunting success, not less roaming.
- Housing density was the strongest predictor of home range and roaming extent.

ABSTRACT

Roaming pet cats kill and harass wildlife, hybridise with wild felids, interbreed with feral populations, spread disease or annoy neighbours, and endanger their own welfare by fighting, being struck by vehicles or ingesting poisons. Confinement of pet cats is unpopular, so alternative methods to curb roaming behaviour would benefit wildlife conservation and pet wellbeing. Some owners whose cats participated in previous trials testing the effectiveness of the collar-mounted predation deterrents the CatBib and the Birdsbesafe collar cover (BBS) in reducing predation by pet cats reported that their cats stayed closer to home when wearing the devices. Therefore we tested whether these devices might curb roaming behaviour of pet cats as an alternative to confinement.

Thirty cats participated. Trials occurred in spring and autumn in Perth, Western Australia (southern hemisphere spring – autumn). Cats wore GPS collars for 10 consecutive days, wearing the GPS collar alone for five days and wearing either a CatBib (16 cats) or BBS (14 cats) as well for a further five days. Treatment order was determined randomly for each cat. We represented cats’ home ranges with 95 % kernel density estimates (KDE) (100 % minimum convex polygon (MCP) provided for comparison with other studies) and 50 % KDE (core home range). We also used data for all cats when not wearing either predation deterrent, plus data on a further four cats, to determine the relative effect of sex, age, night confinement, housing density, number of days of rain, total rainfall, and mean maximum temperature on both estimates of home range size.

Neither device reduced home range significantly. The mean home range (95 % KDE) was 2.79 ha with the CatBib and 2.46 ha without. Figures for the core home range (50 % KDE) were 0.63 ha and 0.71 ha respectively. The mean home range (95 % KDE) with the BBS (where the sample included fewer cats from lower housing densities) was 0.58 ha and 0.50 ha without. The means for the core home range (50 % KDE) were 0.15 ha and 0.14 ha respectively. When cats were not wearing either device, 95 % and 50 % KDE were predicted most strongly by housing density, presumably a surrogate for cat density.

Owners may use a CatBib or BBS to curtail their cat’s hunting behaviour, but curtailing roaming behaviour needs another solution. Confinement, although unpopular, remains the most effective option where unwanted roaming is a problem.

Keywords

pet cat; Felis catus; cat husbandry; CatBib; Birdsbesafe; home range
1 INTRODUCTION

Wandering cats hunt wildlife (Baker et al., 2005), compete for prey with higher order consumers (George, 1974), spread disease to humans or wildlife (Torrey and Yolken, 2003; Eymann et al., 2006; Izawa et al., 2009), exert sub-lethal effects such as changes in behaviour and reduced reproductive success via fear of predation (Preisser et al., 2005), hybridise with wild felids (Beaumont et al., 2001) or breed with stray and feral cats (Jongman, 2007) to maintain feral populations. They may also be a nuisance to neighbours; disturbing dogs, attacking pet birds, spraying, digging in gardens, fighting (including with other pet cats) and walking on cars (Jongman, 2007; Toukhsati et al., 2012). In some cases, legislation includes measures that can be taken against such ‘nuisance animals’ (Lilith et al. 2007 and included references) or offended citizens may take action directly (e.g., examples in Grayson and Calver 2004).

Wandering behaviour also impacts cat welfare. Traffic accidents are one of the highest causes of mortality for pet cats, especially juveniles (Rochlitz et al., 2001; Egenvall et al., 2009). Death or injury of cats in these events had considerable financial and emotional costs to owners in one region of the UK (see Rochlitz, 2004a; b). Given the high frequency of road accident trauma for cats elsewhere (Engenvall et al., 2009, Calver et al., 2013) financial and emotional costs are likely to be widespread. It can also be difficult to reunite lost cats with their owners. Lord et al. (2007) found that only 53 % of lost cats were recovered, including those that returned on their own. Some animal agencies in the US note that only 2-5 % of pet cats are reclaimed by their owners (Humane Society of the United States, 2011). It is possible that some cats are euthanized before their owners contact the agencies because of the expectation that cats may wander and go missing for a few days before returning home (Lord et al., 2007). Wandering of entire (not desexed) cats also results in unwanted litters. New et al. (2004) estimated that 68 % of cat litters in the US during 1996 were unplanned by their owners. They estimated that 150,000 kittens were euthanized and 320,000 were surrendered to animal shelters. Loyd et al. (2013) found that many cats exhibit risky behaviours when roaming, such as crossing busy roads, encountering strange cats, eating and drinking substances away from home, exploring drains and entering confined spaces beneath houses.
Despite these issues, cat owners are often reluctant to confine their cats at all times (Grayson et al., 2002; Dabritz et al., 2006; Lilith, 2007; Sims et al., 2008). While the incidence of confinement of pet cats may be as high as 76 % in Singapore (Gunaseelan et al., 2013), this compares to 50 - 60 % in the USA as a whole (Rochlitz, 2005), and less than 10 % in Australia (REARK, 1994b; a; McHarg et al., 1995; Perry, 1999; Lilith et al., 2006) and the UK (Sims et al., 2008). Estimates of the home ranges of free-roaming pet cats vary from 0.24 ha (Kays and DeWan, 2004) to 0.92 ha (Meek, 2003) to 2.63 ha (Morgan et al., 2009), with substantial variation between individuals (Barratt, 1997). Cats living in rural areas or adjacent to remnant bushland have larger home ranges than cats in highly urbanised environments (Lilith et al., 2008; van Heezik et al., 2010), probably because of fewer contacts with other cats than in more densely populated areas. If an inexpensive collar-mounted device could reduce roaming, then predation, disease transmission and general nuisance attributed to pet cats could be reduced, as well as the risks of road accidents, fighting and unwanted litters. While owners may have reservations about the safety of collars (Lord et al., 2010), the risk of serious injury or death is low for correctly fitted and maintained safety collars (Brinkley, 2007; Lord et al., 2010; Calver et al., 2013).

The collar-mounted pounce protector the CatBib marketed by Cat Goods LLC, Portland, OR, USA (Cat Goods Inc., 2000) and the Birdsbesafe® cat collar cover marketed by Birdsbesafe LLC, Duxbury, VT, USA (Birdsbesafe LLC, 2009) (hereafter BBS) may be devices that reduce roaming. The CatBib reduces the number of vertebrate prey caught by pet cats, presumably by physically interfering with coordination of the paws during prey capture (Calver et al., 2007). However, it may be that cats wearing CatBibs are not travelling to areas where they encounter wildlife. Calver et al. (2007) found that the number of cats reported as wandering (missing from home for at least two days) while wearing a CatBib was less than that of cats that were not. Although the result was not statistically significant, the authors suggested it might indicate a change in the roaming behaviour for some cats while wearing the device that warrants a more rigorous test of the hypothesis than anecdotal reports. The BBS is a bright collar cover that reduces the number of bird and lizard prey by providing a visual warning of the cat's presence, allowing prey to escape (Hall et al., 2015; Willson et al., 2015). During the Hall et al. (2015) study, 20% of owners anecdotally reported that cats wearing the BBS changed their roaming behaviour either by staying closer to home or
staying out more than normal. If evidence of changes in roaming behaviour can be found, the CatBib and the BBS could potentially offer an affordable option to owners to reduce their cats' wandering behaviour without confining them, as well as protecting wildlife from predation. Therefore, this study used GPS radio-tracking to determine the home range size of 30 cats with and without a BBS or CatBib across a range of settings (rural-suburban-urban), evaluating evidence for shifts in roaming behaviour because of wearing the device, device type, and setting. We further evaluated environmental covariates of home range with a broader sample of cats to determine important factors predicting home range size. Findings underpin prior studies by investigating the mechanisms by which anti-predation devices function, potentially improving pet welfare and conservation outcomes.

2 METHODS

2.1 ETHICS STATEMENT

The study was conducted under permit R2468/12 of the Murdoch University Animal Ethics Committee and permit 2012/055 of the Murdoch University Human Research Ethics Committee.

2.2 STUDY SITE

The study was conducted from October 2012 to May 2013 and September 2013 to April 2014 (southern hemisphere spring – autumn) in Perth, Western Australia. This city experiences a Mediterranean climate with hot, dry summers and cool, wet winters. The study was not conducted through winter, based on the assumption that many cats would not spend as much time outside or travel as far in cold, wet conditions (Goszczyński et al., 2009).

2.3 SELECTION OF CATS, TRIAL DESIGN AND ENVIRONMENTAL VARIABLES

Thirty-five cats were involved in the study after their owners were recruited through personal contact with the authors or were suggested by another owner already recruited to the study. A cat was only accepted if the combined weight of the GPS collar and CatBib or BBS was less than 5 % of its weight (i.e. the cat weighed over 3 kg).

All GPS collars, CatBibs and BBS were fitted during a home visit in which the importance of correct fit for safety was emphasised to owners. Twenty-nine cats were fitted with GPS
collars for 10 consecutive days. Each cat alternated between five days wearing the GPS collar alone and five days wearing either a CatBib (15 cats) or BBS (14 cats) in addition to the GPS collar. The order was determined randomly for each cat. A further cat (Boo) in the CatBib group did not complete 10 days consecutively because he contracted an eye infection during the study and data collection was paused until after he recovered. Seven cats wore the CatBib first and nine wore it second, while the respective numbers for the BBS were seven and seven. This design ensured that all cats spent a period with and without the CatBib/BBS, as well as controlling for possible effects of the sequence of treatments.

A further five cats were withdrawn from the study before they had completed the trial because the owners felt the cats were unhappy. Four of these cats had completed part of the trial with the GPS collar only and these data were used for some of the analyses (see below). Data from one cat were excluded because she only completed four days with the GPS collar and BBS.

All cats were desexed prior to the study. Of the 16 cats that trialled the CatBib, 13 were male and three were female. The average age was seven and the range one to 18 years old. Of the 14 cats that completed the trial with the BBS, eight were male and six were female. The average age was six years and ranged from two to 12 years old. Of the four cats that were used for roaming predictor analysis only, all were male and the average age was two, ranging from one to four years old (Table 1). Based on owners' assessments, nine cats were defined as hunters (i.e. bring at least one prey item home per fortnight) and eighteen cats did not currently hunt regularly (but may have been good hunters when they were younger) or did not hunt at all. No information on hunting behaviour was provided for seven cats. Sixteen cats were kept inside each night (N=16). We also recorded the environmental variables of housing density, number of days of rain, total rainfall, and mean maximum temperature. Weather variables were determined from the records of the closest Bureau of Meteorology station to each cat’s household.

2.4 GPS COLLARS

Five GPS collars (model G2C128A, Sirtrack Ltd., Havelock North, New Zealand) were used to track the movement patterns of cats. Each collar weighed approximately 140 g and was powered by a replaceable C123 lithium battery (Fig. 1a). Each collar also included a VHF
radio-transmitter for locating it if it was lost. The GPS attempted to record a location every 30 minutes. The manufacturer specified accuracy indicates that 50 % of fixes are within 5 m of the true location and 90 % are within 8 m.

At the end of each cat's 10-day study, the data were downloaded. The accuracy of each location was indicated by a horizontal dilution of precision (HDOP) value (observed range 1.0 - 12.7). Locations with HDOP values of 9 or above were not used in home range calculations to reduce outlier influence (Metsers et al., 2010).

2.5 CATBIBS

CatBibs are made of neoprene and come in several colours. Turquoise CatBibs were used in this study (Fig. 1b) for consistency and to minimise additional sources of variation in the experiment. CatBibs interfere with the capture of prey (Cat Goods Inc., 2000), while not impeding other cat activities such as eating, playing or grooming (Calver et al., 2007; Cat Goods Inc., 2000).

2.6 BIRDSBESAFE® (BBS)

The BBS is a 50 cm length of brightly coloured cloth formed into a tube. It slips over a standard cat safety collar to appear as a brightly coloured ‘ruff’ or flared-out encircling cloth ‘clown collar’ about 5 cm wide (Fig. 1c). Multiple colourful prints are available; for consistency we selected the design with rainbow stripes of red, yellow, grey, white and fuchsia. The BBS provides a visual warning to prey of a stalking cat’s presence (Birdsbesafe LLC, 2009). Birds and lizards have excellent colour vision and thus should see the BBS from a distance and escape more readily (Hall et al., 2015; Willson et al., 2015).

2.7 ESTIMATION OF HOME RANGE AND DATA ANALYSIS

Estimations of cat home range were calculated in Ranges Software version 8 (Kenward et al., 2009). We estimated the home range with 95 % kernel density (95 % KDE) and used the 50 % kernel density (50 % KDE) to represent the core home range/areas of high usage, calculating KDE by the fixed method with reference bandwidth (Metsers et al., 2010). We also provide the 100 % minimum convex polygon (MCP) for comparison with other studies. We used incremental area analysis to determine whether the home ranges were fully revealed in the time frame. We did not distinguish diurnal and nocturnal fixes, because
some cats were confined at night. Instead, we included night confinement as a predictor variable in the analysis.

Our study objectives were to determine if 95 % and 50 % KDE of domestic cat home range varied when cats wore a BBS or CatBib, and to determine the influence of individual- and environmental-based covariates on home range. To achieve this we employed an information theoretic approach (Burnham and Anderson, 2002) whereby we evaluated a priori hypotheses and covariates using Akaike’s information criterion applied to linear mixed models. Analyses were conducted in two sets: first, we evaluated the dataset of 30 cats wearing anti-predation devices, and second we analysed data from 34 cats not wearing the devices to further identify important covariates of home range size. In all instances we followed the suggestions of Zuur et al. (2009) for data exploration, model fit and checking for violations of assumptions. Home range was LN-transformed in all analyses, but no covariates required transformation. All analyses were conducted in R 3.1.2 (R Core Team 2014) using packages lme4 (Bates et al., 2015), MuMIn (Bartoñ, 2015) and ggplot2 (Wickham, 2009). In all cases we report models with Akaike weights >5 % and parameter estimates of the top-selected model.

To evaluate the effect of the BBS and CatBib on home range we had a sample of 30 cats with home range estimated for periods of the device being on or off; thus we obtained 60 observations of home range size. In addition to our experimental manipulations (device on-off, device type) we wanted to evaluate covariates associated with each animal (age, original sex, in-out at night, order of treatment) and the environment (housing density, total rain during measurement period, number of days of rain, mean maximum temperature). To account for two observations per cat, we used a mixed effects model where the identify of each cat was treated as random and other predictors as fixed. We then constructed a series of models where device on-off (the a priori question of the study) was included in every model and all other covariates were evaluated using all subsets regression. Because of the modest size of the dataset, we limited the maximum number of predictors per model to a maximum of three to avoid overfitting; we had no expectation of interactions among predictors and saw no evidence of interactions in plots of the data. Therefore we only considered additive models. Models were ranked using AICc (AIC corrected for small sample size) and models with weights greater than 5 % retained. For our broader set of cats (N=34)
without predation deterrents we only had one observation per cat and therefore applied a simple linear model. As before, we used an all subsets approach where we limited the maximum number of predictors to three to prevent overfitting.

3 RESULTS

3.1 CHARACTERISTICS OF CATS IN THE STUDY AND ENVIRONMENTAL CONDITIONS

The mean housing density for cats in the study was 18 dwellings/ha with the majority of cats (23) living in areas of 15-20 houses/ha, which is typical of general suburbia with detached housing in Perth. The lower average housing density for cats in trialling the CatBib is driven by three cats (two male and one female) that lived on rural properties (Table 1).

The mean maximum daily temperature during the study was 27.3 ºC (Table 1). Although it was hotter during the BBS trial than the CatBib trial, 30.3 ºC and 25 ºC respectively, there was no substantial difference in temperature for cats with or without a BBS/CatBib in each trial. During the CatBib trial, the mean rainfall for all cats was 17 mm irrespective of whether or not cats were wearing the CatBib. Female cats experienced more rainfall on average, with a mean of 37 mm with the CatBib and 30 mm without over 1.7 and 1.3 days respectively. Male cats in the CatBib trial experienced much less rainfall overall and less variation in the amount of rain between treatments (12.9 mm with the CatBib and 14.8 mm without) over 1.5 and 1.3 days respectively. It was much drier for the cats trialling the BBS, with most cats (9) experiencing no rainfall at all. On average, cats in the BBS trial experienced 2.3 mm with the BBS and 2.9 mm without over 0.6 days each. Females experienced slightly more rain than males (Table 1).

Individual characteristics for each cat are provided in online Appendix 1.

3.2 INFLUENCE OF THE CATBIB AND BBS ON HOME RANGE SIZE

Incremental area analysis showed that home range estimates for cats when wearing or not wearing a CatBib or BBS had plateaued, with the exception of two cats wearing the BBS. Thus the BBS home ranges reported are modest underestimates.

Home range sizes for 95 % and 50 % KDE of cats with and without a CatBib or BBS were similar (Table 2; Fig. 2; see online Appendix 2 for home ranges for each individual cat). The top models for both 95 % KDE and 50 % KDE included housing density but not the type of
device (Table 3). Akaike weight of the top model for 95 % KDE was 0.32 and 0.33 for 50 % KDE (Table 3). Other top-ranked models (sequence identical across 95 % and 50 % KDE) included covariates of type of anti-predation device, order, sex, and in-out at night with Akaike weights spanning 0.17 to 0.06 (Table 3). Within the top model, the estimated effect of a CatBib or BBS being on was not significant (95 % KDE: 0.02, SE=0.10, t=0.2, p=0.39; 50 % KDE: 0.01, SE=0.08, t=0.1, p=0.39) (Fig. 2) (thus the fact that two cats' home ranges had not plateaued when wearing the BBS could not have hindered a significant result). The effect of housing density was similar for 95 % KDE (Fig. 3; estimate -0.08, SE=0.02, t=4.1, p<0.001) and 50 % KDE (estimate -0.07, SE=0.02, t=4.2, p<0.001).

3.3 ENVIRONMENTAL COVARIATES

Using our dataset of 34 cats not wearing a CatBib or BBS, top models predicting 95 % and 50 % KDE of home range size were identical, including housing density and total rain during the measurement period (Table 4). Top models had weights of 0.28 and 0.29 for 95 % and 50 % KDE respectively (Table 4). The age covariate was present in both second-ranked models, both of which had higher weights, while other covariates (mean maximum temperature, number of days with rain, sex) had markedly lower support (Table 4). As with cats wearing a CatBib or BBS, housing density represented the largest effect with a negative estimate (Fig. 4; 95 % KDE: -0.09, SE=0.01, t=6.2, p<0.001; 50 % KDE: -0.09, SE=0.01, t=6.4, p<0.001). Total rainfall during the measurement also had support in the data with a negative effect on home range size (95 % KDE: -0.02, SE=0.01, t=2.6, p=0.02; 50 % KDE: -0.03, SE=0.01, t=3.0, p=0.01). However, low rain occurred during the period of measurement of cats at the lowest housing densities, suggesting caution in inference (Fig. 4). Mean home range sizes for all cats (± SE) are given in Table 2.

4 DISCUSSION

4.1 INFLUENCE OF THE CATBIB AND THE BBS ON HOME RANGES

Despite indications from both Calver et al. (2007) and Hall et al. (2015) that the CatBib and BBS may reduce pet cats' roaming behaviour, this was not the case in this first experimental test of the hypothesis that these devices reduce pet cats' home ranges. Importantly, this
indicates that lower prey capture rates are not caused by reduced roaming, further strengthening the inference of prior studies concluding that the CatBib interferes with prey capture and the BBS alerts prey with good colour vision. It also means that owners cannot use either device as a tool to reduce roaming.

Approximately 50% of cats hunt at some time in their lives (Paton, 1991; REARK, 1994b; Perry, 1999), but this study included a large proportion of cats that were not hunting regularly (at least, were not bringing prey home for their owners to report). However, both Calver et al. (2007) and Hall et al. (2015) used cats known to bring home at least one prey a fortnight on average in their studies of the effectiveness of the CatBib and BBS in reducing predation on wildlife. Corroborative evidence of the devices reducing hunting success could include increased appetite because of lower prey capture or increased roaming time to compensate for lower success. In Hall et al. (2015) many of the cat owners who reported that their cats came home earlier or stayed closer to home also recounted that their cats ate more food during this time. Furthermore, two cats were reported as staying out more (Hall et al., 2015). If hunting success is a factor in the change of roaming behaviour for the cats reported in the Calver et al. (2007) and Hall et al. (2015) studies, it may not have been relevant to many of the cats in this study and therefore we would not see any effect overall.

### 4.2 FACTORS PREDICTING HOME RANGE

The home ranges we report are within the ranges of other studies in Australia and internationally (Online Appendix 3). Consistent with our results, other studies have reported that housing density is a strong limiting factor on home range, with cats living in rural areas or on the urban fringe having larger home ranges than cats in inner-city suburbs (Lilith et al., 2008; Morgan et al., 2009; Metsers et al., 2010; van Heezik et al., 2010). There are two principal explanations. One is that rural areas and urban fringes are closer to large areas of natural vegetation through which cats can move unimpeded. Morgan et al. (2009) found that cats living closer to a wetland in New Zealand had larger home ranges and travelled further into the wetland than cats living further away and van Heezik et al. (2010) found that cats located next to any open green space had larger home ranges. In this study, cats in the CatBib trial had a higher mean home range because several of these cats lived in rural areas...
compared to the BBS trial where all of the cats lived in suburban settings with reduced access to green space.

The second factor is the density and distribution of cat-owning households. Domestic cats have a complex social structure. In cat colonies, female cats tend to have smaller home ranges and live in groups of related cats that are clumped around food sources. Male cats have larger home ranges based on the distribution of females, with subordinate male cats having smaller home ranges (Liberg, 1984). Female cats often have completely overlapping home ranges with related females, but very little overlap with unrelated females except around food (Liberg, 1984). The home ranges of male cats overlap more, presumably because their resource (females) is dispersed, unpredictable and harder to defend (Liberg, 1984). Although this study and the others mentioned in Online Appendix 3 are predominantly concerned with pet cats, which entail different living conditions than colonies (e.g. many cats in multiple cat households are unrelated and most cats in the studies are desexed), cats still adhere to a social structure. Barratt (1997) found that related cats in the same household had completely overlapping home ranges, in contrast to unrelated cats from the same residence that had overlapping core home ranges but tended to have non-overlapping outer home ranges. Barratt (1997) also found that there was no overlap of home range between females from separate residences, but some overlap in the home ranges of males and males and females of separate homes. Males from separate homes also appeared to actively avoid each other’s core areas (Barratt, 1997). Meek (2003) also found that cats from different households did not overlap in core areas. Thus, given strong evidence of cat density and distribution influencing roaming behaviour, it is reasonable to expect that in areas of higher housing density and therefore higher cat densities, home ranges will be reduced.

All cats in our study were desexed and there was no significant effect of sex on home range though, on average, male cats had slightly larger home ranges than females, which was consistent with previous studies (Lilith et al., 2008; Morgan et al., 2009; Hansen, 2010). It is very unlikely that the home range of male desexed cats depends on the distribution of females. Barratt (1997) suggests that the home ranges of male desexed cats are more likely to be based on food distribution (i.e. their home where food is provided). Guttila and Stapp (2010) found no effect of desexing on the home ranges of unowned cats and Horn et al.
(2011) found that the one desexed male cat in their study had a smaller home range to the unowned entire male cats, but that the one desexed female had an average home range comparable to the unowned entire female cats. However, it may be that once a cat has already established its home range, desexing may have no effect. It may have a much larger effect on pet cats that have not established their home range before being desexed. However, this would be difficult to test.

This study found no strong evidence of an impact on home range of whether a cat was kept in at night or allowed to roam freely all the time. This was unexpected, because several other studies indicate that cats roam significantly further at night time than during the day (Barratt, 1997; Meek, 2003; Hansen, 2010; Metsers et al., 2010; Thomas et al., 2014). However, the particular timing of when owners decide to bring their cat in is variable. Many of the cats that are kept in at night may not actually be confined until after dark, or may be let out very early in the morning if they wake and annoy their owners.

We found some evidence of rain reducing roaming behaviour and thus home range estimates. These results are constrained by the fact that cats in the lowest housing density condition were tracked without devices during a dry period. Therefore, while we found no formal statistical issues (variance inflation, severe co-linearity of covariates), we are cautious in our inference. However, the negative impact of rain on roaming behaviour during a 5-day period does fit with general expectations. This effect might have been negated if cats had worn collars for longer periods, thereby exceeding the typical timeframe of weather fronts (~2-4 days) and reducing potential influence.

4.3 VALIDITY OF THE STUDY SAMPLE AND HOME RANGE ESTIMATES

The sample of cats used in this study were recruited via personal contact with owners raising a potential bias in the sample. Despite this, the sample of animals represented a broad range of ages (Table 1) and housing densities (Figure 3). Further, the study was conducted across a range of weather conditions (Table 1, Figure 4). Therefore we feel that the sample of cats in the study offers strong inference in the context of assessing movement in relation to predation deterrent device, housing density, and weather conditions. Other, more subtle, socioeconomic details are beyond the scope of the present study.
After we completed our data collection Coughlin and van Heezik (2014) found that heavy GPS collars (>3 % of body mass) reduced home ranges by approximately 25% compared to the lightest collars. Given that our collars fall into the heavy range, our data may be underestimates of the true home range. The possible underestimate does not impact the inference of this study because all cats wore the same GPS collar type. There may be complex interactions between environmental conditions and collar weight in our assessment of the influence of environmental conditions on home range, but that would be speculation in the absence of evidence. The collar weight issue is relevant to all but the most recent studies of home range that have been able to take advantage of the latest lightweight collars.

4.4 IMPLICATIONS FOR ENVIRONMENTAL MANAGEMENT, CAT HUSBANDRY AND CAT WELFARE

The manufacturers of both the CatBib and the BBS claim that the devices do not curtail a range of normal behaviours of cats other than hunting (Cat Goods Inc., 2000; Birdbesafe LLC, 2009)). Our results corroborate these claims, at least in relation to roaming. This may be important for owners considering using either device, but having reservations about whether or not the device may impede the free movement of their animals. Neither device is an option for owners wishing to restrict their cats’ roaming.

Owners wishing to restrict their cats’ roaming cannot resort to a CatBib or BBS and need to keep their cats confined to their property. However, this is unpopular with many owners (Grayson et al., 2002; Dabritz et al., 2006; Lilith, 2007; Sims et al., 2008). Rochlitz (2005) suggests that the main concern with an indoor environment is that it can be impoverished, predictable and monotonous compared to outdoors. This stresses and bores the cat or contributes to type 2 diabetes (Slingerland et al., 2009). However, the environment of indoor cats can be enriched by companionship from humans, other cats and other pets; toys, climbing structures or food games; comfortable resting places; and sensory stimulation such as an outlook from a window (Ellis, 2009). Cats can be successfully housed indoors or with access to outdoor enclosed cat runs provided they are used to these conditions from an early age (Rochlitz, 2005), although cats used to outdoor access may have difficulty adapting to an entirely indoor existence (Hubrecht and Turner, 1998).
5 Conclusion

The suggestions from earlier studies that the collar-mounted predation deterrents the CatBib and the BBS might reduce the roaming behaviour of pet cats were not supported by this experimental test. The most substantial influence on roaming behaviour was housing density, probably operating as a surrogate for the density of other cats in the vicinity. Owners who want to use either a CatBib or BBS to curtail their cat’s hunting behaviour but not restrict its roaming can do so with confidence, while owners wishing to curtail roaming behaviour need to find another solution. Confinement, although unpopular, remains the most effective option for reducing the environmental, social and animal welfare problems associated with roaming cats.

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Lilith, M., (PhD thesis) 2007. Do pet cats (*Felis catus*) have an impact on species richness and abundance of native mammals in low-density Western Australian suburbia? Murdoch


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Figure captions

Fig. 1  Timba wearing (a) GPS collar only, (b) GPS collar with CatBib, (c) GPS collar with BBS.

Fig. 2  Home ranges (ha) of cats represented as 95 % KDE (kernel density estimate) and 50% KDE when cats were wearing or not wearing a device (CatBib or a BBS). Error bars indicate 95 % CL back transformed from the logarithmic data analysed.

Fig. 3  Home ranges (ha) of cats represented as 95 % KDE (kernel density estimate) at different housing densities when cats (N=30 plus an additional 4 never fitted with CatBib/BBS) were not wearing either a CatBib or BBS.

Fig. 4  Home ranges (ha) of cats represented as 95 % KDE (kernel density estimate) under different rainfall conditions when cats were not wearing either a CatBib or BBS. Shape indicates the quartile of housing density for each cat in the study; rainfall was not distributed evenly across housing densities.
Fig 1
Fig 2

![Graph showing home range comparison between BBS and Cat Bib collars at 50% and 90% KDE. The graph displays data points for collar on/off status as well.](image-url)
Fig 4

Quartile of Housing Density
- First
- Second
- Third
- Fourth

Home range (ha)

Total rain (mm)
Table 1. Characteristics of cats and environmental conditions during the trials

<table>
<thead>
<tr>
<th>Trial (n)</th>
<th>Age of cat (mean ± s.e.)</th>
<th>Mean maximum temperature (°C) (mean ± s.e.)</th>
<th>Mean total rainfall (mm) (mean ± s.e.)</th>
<th>Mean no. of days with rain (mean ± s.e.)</th>
<th>Mean housing density (dwellings/h a) (mean ± s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CatBib</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females with (3)</td>
<td>8.2 ± 3</td>
<td>24.1 ± 2.3</td>
<td>37 ± 9.4</td>
<td>1.7 ± 0.7</td>
<td>11.8 ± 5.7</td>
</tr>
<tr>
<td>Females without (3)</td>
<td>23.1 ± 1.4</td>
<td>30.5 ± 16</td>
<td>1.3 ± 0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males with (13)</td>
<td>7 ± 1.3</td>
<td>25.2 ± 1.3</td>
<td>12.9 ± 4.6</td>
<td>1.5 ± 0.4</td>
<td>18.1 ± 2.7</td>
</tr>
<tr>
<td>Males without (13)</td>
<td>25.2 ± 1.3</td>
<td>14.8 ± 5</td>
<td>1.3 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All with (16)</td>
<td>7.2 ± 1.1</td>
<td>25.0 ± 1.1</td>
<td>17.5 ± 4.7</td>
<td>1.5 ± 0.4</td>
<td>16.9 ± 2.5</td>
</tr>
<tr>
<td>All without (16)</td>
<td>24.8 ± 1.1</td>
<td>17.7 ± 5</td>
<td>1.3 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birdsbesafe</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Females with (6)</td>
<td>3 ± 0.4</td>
<td>29.5 ± 2.4</td>
<td>4.2 ± 3.1</td>
<td>1 ± 0.7</td>
<td>22.1 ± 2.6</td>
</tr>
<tr>
<td>Females without (6)</td>
<td>29.4 ± 2</td>
<td>4.5 ± 4.5</td>
<td>0.7 ± 0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males with (8)</td>
<td>8.3 ± 1.3</td>
<td>30.8 ± 1.4</td>
<td>0.9 ± 0.9</td>
<td>0.3 ± 0.3</td>
<td>21.6 ± 4</td>
</tr>
<tr>
<td>Males without (8)</td>
<td>31.0 ± 1.7</td>
<td>1.8 ± 1.1</td>
<td>0.5 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All with (14)</td>
<td>6 ± 1</td>
<td>30.2 ± 1.3</td>
<td>2.3 ± 1.4</td>
<td>0.6 ± 0.3</td>
<td>21.8 ± 2.5</td>
</tr>
<tr>
<td>All without (14)</td>
<td>30.3 ± 1.3</td>
<td>2.9 ± 2</td>
<td>0.6 ± 0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All cats without a predation deterrent device</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Females (9)</td>
<td>4.7 ± 1.3</td>
<td>27.3 ± 1.7</td>
<td>13.2 ± 6.9</td>
<td>0.9 ± 0.5</td>
<td>18.7 ± 2.9</td>
</tr>
<tr>
<td>Males (25)</td>
<td>6.7 ± 0.9</td>
<td>27.3 ± 1.1</td>
<td>10.4 ± 3</td>
<td>1.3 ± 0.4</td>
<td>18 ± 2.2</td>
</tr>
<tr>
<td>All cats (34)</td>
<td>6.2 ± 0.7</td>
<td>27.3 ± 0.9</td>
<td>11.1 ± 2.8</td>
<td>1.2 ± 0.3</td>
<td>18.1 ± 1.7</td>
</tr>
</tbody>
</table>
Table 2. Home range, core areas, mean number of successful fixes and percentage of successful fixes and for cats with and without a CatBib, with and without a BBS, and for all cats without either predation deterrent fitted. Sample sizes are shown in parentheses.

<table>
<thead>
<tr>
<th>Trial (n)</th>
<th>Home range (ha) (mean ± s.e.)</th>
<th>Core range (ha) (mean ± s.e.)</th>
<th>Mean number of successful fixes (mean ± s.e.)</th>
<th>Fixes as a % of all possible fixes (mean ± s.e.)</th>
<th>% fixes successful&lt;sup&gt;c&lt;/sup&gt; (mean ± s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CatBib</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Females with (3)</td>
<td>7.52 ± 6.52</td>
<td>6.36 ± 5.85</td>
<td>1.80 ± 1.00</td>
<td>118.3 ± 17.9</td>
<td>57.4 ± 8.3</td>
</tr>
<tr>
<td>Females without (3)</td>
<td>8.84 ± 7.95</td>
<td>6.43 ± 6.05</td>
<td>2.03 ± 1.93</td>
<td>131.3 ± 17.0</td>
<td>60.6 ± 8.6</td>
</tr>
<tr>
<td>Males with (13)</td>
<td>4.01 ± 1.39</td>
<td>1.97 ± 1.07</td>
<td>0.48 ± 0.25</td>
<td>94.6 ± 8.3</td>
<td>44.3 ± 4.1</td>
</tr>
<tr>
<td>Males without (13)</td>
<td>3.14 ± 1.26</td>
<td>1.54 ± 0.72</td>
<td>0.41 ± 0.19</td>
<td>92.9 ± 7.7</td>
<td>45.1 ± 3.8</td>
</tr>
<tr>
<td>All with (16)</td>
<td>4.69 ± 1.56</td>
<td>2.79 ± 1.34</td>
<td>0.72 ± 0.29</td>
<td>99.1 ± 7.7</td>
<td>46.7 ± 3.8</td>
</tr>
<tr>
<td>All without (16)</td>
<td>4.20 ± 1.72</td>
<td>2.46 ± 1.22</td>
<td>0.71 ± 0.38</td>
<td>100.1 ± 7.8</td>
<td>48.0 ± 3.7</td>
</tr>
<tr>
<td>BBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females with (6)</td>
<td>0.72 ± 0.12</td>
<td>0.43 ± 0.14</td>
<td>0.16 ± 0.07</td>
<td>79.5 ± 8.2</td>
<td>39.0 ± 4.0</td>
</tr>
<tr>
<td>Females without (6)</td>
<td>0.75 ± 0.16</td>
<td>0.50 ± 0.18</td>
<td>0.16 ± 0.06</td>
<td>73.0 ± 7.9</td>
<td>34.8 ± 3.8</td>
</tr>
<tr>
<td>Males with (8)</td>
<td>1.31 ± 0.71</td>
<td>0.69 ± 0.40</td>
<td>0.15 ± 0.06</td>
<td>93.2 ± 22.2</td>
<td>48.1 ± 9.8</td>
</tr>
<tr>
<td>Males without (8)</td>
<td>1.25 ± 0.64</td>
<td>0.50 ± 0.23</td>
<td>0.13 ± 0.04</td>
<td>98.1 ± 14.4</td>
<td>47.3 ± 6.5</td>
</tr>
<tr>
<td>All with (14)</td>
<td>1.06 ± 0.41</td>
<td>0.58 ± 0.23</td>
<td>0.15 ± 0.04</td>
<td>87.4 ± 12.1</td>
<td>44.2 ± 5.8</td>
</tr>
<tr>
<td>All without (14)</td>
<td>1.04 ± 0.37</td>
<td>0.50 ± 0.14</td>
<td>0.14 ± 0.04</td>
<td>87.4 ± 8.7</td>
<td>42.0 ± 4.3</td>
</tr>
<tr>
<td>All cats without a device</td>
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<td></td>
<td></td>
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<tr>
<td>Females (9)</td>
<td>3.45 ± 2.66</td>
<td>2.48 ± 2.01</td>
<td>0.78 ± 0.64</td>
<td>92.4 ± 12.0</td>
<td>43.4 ± 5.5</td>
</tr>
<tr>
<td>Males (25)</td>
<td>3.41 ± 1.12</td>
<td>2.06 ± 0.87</td>
<td>0.69 ± 0.38</td>
<td>96.2 ± 6.0</td>
<td>46.1 ± 2.8</td>
</tr>
<tr>
<td>All cats (34)</td>
<td>3.42 ± 1.06</td>
<td>2.17 ± 0.82</td>
<td>0.72 ± 0.32</td>
<td>95.2 ± 5.4</td>
<td>45.4 ± 2.5</td>
</tr>
</tbody>
</table>

<sup>a</sup> Successful fixes are those with an HDOP value <9. See section 2.3 for further explanation

<sup>b</sup> number of fixes (irrespective of success)/ total number of fixes that could have been received in a 5-day period (i.e. 1 point every 30 mins = 240 points in 5 days)

<sup>c</sup> the number of successful fixes / the number of fixes received
Table 3. Model selection results for predictors of home range size (95 and 50 % kernels) of cats (N=30) wearing either a CatBib or BBS antipredation device in Perth, Western Australia. Models with the lowest AICc and highest $w_i$ have the strongest support.

<table>
<thead>
<tr>
<th></th>
<th>Model†</th>
<th>k</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>$w_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>95 % Kernel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density</td>
<td>5</td>
<td>153.6</td>
<td>0</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Device Type</td>
<td>6</td>
<td>154.9</td>
<td>1.3</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Order</td>
<td>6</td>
<td>156.0</td>
<td>2.4</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Sex</td>
<td>6</td>
<td>156.0</td>
<td>2.4</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + InOut at Night</td>
<td>6</td>
<td>156.1</td>
<td>2.5</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>50 % Kernel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density</td>
<td>5</td>
<td>138.6</td>
<td>0</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Device Type</td>
<td>6</td>
<td>140.4</td>
<td>1.8</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Order</td>
<td>6</td>
<td>141.0</td>
<td>2.4</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Sex</td>
<td>6</td>
<td>141.1</td>
<td>2.5</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + InOut at Night</td>
<td>6</td>
<td>141.2</td>
<td>2.6</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>DeviceOnOff + Housing Density + Age</td>
<td>6</td>
<td>142.1</td>
<td>3.5</td>
<td>0.06</td>
</tr>
</tbody>
</table>

†Full model for cats wearing a CatBib or BBS: $\ln(\text{Kernel Size}) \sim \text{Intercept} + \text{collarOn-Off} + \text{Housing Density}$. Models presented are those with a minimum of 5% model weights given the model set.
Table 4. Model selection results for predictors of home range size (95 and 50 % kernels) of cats (N=34) not wearing a CatBib or BBS in Perth, Western Australia. Models with the lowest AIC<sub>c</sub> and highest w<sub>i</sub> have the strongest support.

<table>
<thead>
<tr>
<th>Model†</th>
<th>k</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>w&lt;sub&gt;i&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>95th Kernel</td>
<td>Housing Density + Total Rain</td>
<td>4</td>
<td>93.8</td>
<td>0</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Age</td>
<td>5</td>
<td>94.2</td>
<td>0.5</td>
<td>0.22</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Mean Max Temp</td>
<td>5</td>
<td>96.1</td>
<td>2.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Housing Density + Total Rain + N days rain</td>
<td>5</td>
<td>96.2</td>
<td>2.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Sex</td>
<td>5</td>
<td>96.4</td>
<td>2.6</td>
<td>0.07</td>
</tr>
<tr>
<td>50th Kernel</td>
<td>Housing Density + Total Rain</td>
<td>4</td>
<td>91.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Age</td>
<td>5</td>
<td>91.3</td>
<td>0.03</td>
<td>0.29</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Mean Max Temp</td>
<td>5</td>
<td>93.8</td>
<td>2.5</td>
<td>0.08</td>
</tr>
<tr>
<td>Housing Density + Total Rain + Sex</td>
<td>5</td>
<td>93.9</td>
<td>2.6</td>
<td>0.08</td>
</tr>
<tr>
<td>Housing Density + Total Rain + N days rain</td>
<td>5</td>
<td>94.0</td>
<td>2.6</td>
<td>0.08</td>
</tr>
</tbody>
</table>

†Full model: ln(Kernel Size) ~ Intercept + Housing Density + Total Rain. Models presented are those with a minimum of 5% model weights given the model set.