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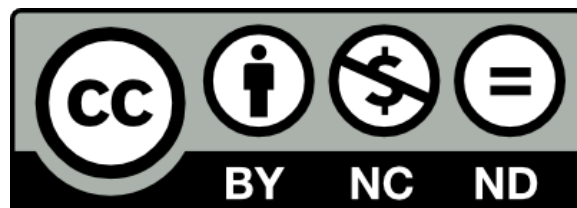
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**Hall, C.M., Fontaine, J.B., Bryant, K.A. and Calver, M.C. (2015)
Assessing the effectiveness of the Birdsbesafe® anti-predation
collar cover in reducing predation on wildlife by pet cats in
Western Australia. Applied Animal Behaviour Science,
173. pp. 40-51.**

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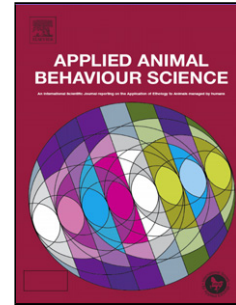


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Accepted Manuscript

Title: Assessing the effectiveness of the Birdsbesafe® anti-predation collar cover in reducing predation on wildlife by pet cats in Western Australia

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PII: S0168-1591(15)00022-2
DOI: <http://dx.doi.org/doi:10.1016/j.applanim.2015.01.004>
Reference: APPLAN 4012

To appear in: *APPLAN*

Received date: 30-7-2014
Revised date: 4-1-2015
Accepted date: 19-1-2015

Please cite this article as: Hall, C.M., Assessing the effectiveness of the Birdsbesafereg^d anti-predation collar cover in reducing predation on wildlife by pet cats in Western Australia, *Applied Animal Behaviour Science* (2015), <http://dx.doi.org/10.1016/j.applanim.2015.01.004>

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Applied Animal Behaviour Science

Assessing the effectiveness of the Birdsbesafe® anti-predation collar cover in reducing predation on wildlife by pet cats in Western Australia

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Highlights

- We assessed the predation deterrent Birdsbesafe® (BBS) in an Australian context.
- Captures of birds and herpetofauna, but not mammals, fell when cats wore a BBS.
- 20 • Rainbow coloured BBS were more effective than red or yellow.
- To date, the BBS is the only predation deterrent protecting herpetofauna.
- The BBS is not suitable where pet cats predate endangered mammals.

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Abstract

Many pet cats hunt and, irrespective of whether or not this threatens wildlife populations, distressed owners may wish to curtail hunting while allowing their pets to roam. Therefore we evaluated the effectiveness of three patterned designs (simple descriptions being rainbow, red and yellow) of the anti-predation collar cover, the Birdsbesafe® (BBS), in reducing prey captures by 114 pet cats over 2 years in a suburban Australian context. The BBS offers a colourful indicator of a cat's presence and should therefore alert prey with good colour vision (birds and herpetofauna), but not most mammals with limited colour vision. We also interviewed the 82 owners of cats in the study about their experience using the BBS and their assessment of the behavioural responses of their cats. In the first year of the study, which focused on the effectiveness of different BBS colours, captures of prey with good colour vision were reduced by 54% (95% CL 43% - 64%) when cats were wearing a BBS of any colour, with the rainbow and red BBS more effective than the yellow when birds were prey. Captures of mammals were not reduced significantly. The second year assessed the rainbow BBS alone, and those data combined with rainbow data in the first year found a significant reduction of 47% (95% CL 43% - 57%) in capture of prey with good colour vision, with no effect of differences across years. We found no evidence that cats maintained a lower predation rate once

the BBS was removed. Seventy-nine per cent of owners reported that their cats had no problems with the BBS and another 17% reported that their cats adjusted within 2 days. Fourteen owners reported that their cats spent more time at home and ate more while wearing the BBS. Two owners
45 reported their cats stayed away from home more while wearing it. Sixty-four per cent of owners using the red collar, 48% using rainbow and 46% using yellow believed that it worked. Overall, 77% of owners planned to continue using the BBS after the study had finished. The BBS is an option for owners wishing to reduce captures of birds and herpetofauna by free-ranging cats, especially where mammalian prey are introduced pests. To date, the BBS is the only predation deterrent that reduces
50 significantly the number of herpetofauna brought home. It is unsuitable where endangered mammalian prey or large invertebrates are vulnerable to predation by pet cats.

Keywords

pet cat; Birdsafe; predation; urban wildlife; *Felis catus*; predation deterrent

1 Introduction

55 Pet cats *Felis catus* are recognised globally as wildlife predators (Baker et al., 2005; Gordon, 2010; Barratt 1997, 1998). Woods et al. (2003) extrapolated from their data that pet cats in Great Britain brought home 92 million prey over 5 months. Loss et al. (2013) estimated the median wildlife mortality by pet cats in the USA at 684 million birds and 1,249 million mammals annually. In Canada, Blancher (2013) estimated that urban pet cats take approximately one-sixth of 100 - 350 million
60 birds (95% of estimates in this range) killed annually by all cats, owned and feral. In South Australia, Paton (1991) argued that pet cats take $\geq 50\%$ of the urban bird population each year and may indirectly impact other species in nearby remnant bushland.

Nevertheless, debate exists regarding whether wildlife populations are endangered by this predation. In Bristol, UK, predation rates of house sparrows *Passer domesticus*, robins *Erithacus*
65 *rubecula* and dunnocks *Prunella modularis* were high compared to their annual productivity,

implying that cat predation regulated their populations (Baker et al., 2005). In Dunedin, New Zealand, population modelling of six bird species with different estimates of cat predation showed that the likelihood of local extirpation with any cat predation was high for blackbirds *Turdus merula*, while fantails *Rhipidura fuliginosa* and that silvereyes *Zosterops lateralis* would only persist if the predation rate was halved (van Heezik et al., 2010). Balogh et al. (2011) found that predation on gray catbirds *Dumetella carolinensis* in suburban Washington D.C., USA, accounted for 79% of all mortalities with 47% attributable to pet cats, but conceded that cats may take prey that would otherwise have died from disease or injury. In Hamilton, south-eastern Australia, Dufty (1994) found that cat predation was the highest cause of mortality for juvenile eastern barred bandicoots *Perameles gunnii* and the second highest cause of mortality for the population after road death. Even the presence of pet cats may alter prey behaviour, contributing to population declines (Beckerman et al., 2007; Bonnington et al., 2013). Other authors argue that pet cats hunt common species that cope with the impacts or take diseased or injured individuals, with the focus on cats deflecting attention from more significant causes of wildlife decline (Fitzgerald, 1990; Fitzgerald and Turner, 2000; Sims et al., 2008; Shochat et al., 2010; Siracusa, 2012).

Calver et al. (2011) argue that documented predation rates and examples of significant risk to prey populations justify precautionary husbandry of pet cats. In some countries many owners always keep their pets indoors (for example, apartment owners in Switzerland (Bradshaw, 1992)), preventing interactions between pet cats and wildlife. If cats are not indoors, then ideally owners should keep them on their properties at all times to reduce predation and nuisance to neighbours (Jongman, 2007; Toukhsati et al., 2012). However, most Australian (Grayson et al., 2002; Lilith, 2007), UK (Sims et al., 2008), USA (Dabritz et al., 2006), New Zealand (Farnworth et al., 2010) and Singaporean owners (Gunaseelan et al., 2013) neither confine their cats indoors nor on their properties. Keeping cats indoors at night reduces predation on nocturnal fauna, but not diurnal prey (Barratt, 1997). Collar-mounted predation deterrents that either impede predatory behaviour or alert prey are another option, although they are not acceptable to everyone (Thomas et al., 2012).

Devices tested experimentally that reduce the numbers of prey brought home by $\geq 50\%$ include bells, pounce protectors and battery-powered alarms (Ruxton et al., 2002; Nelson et al., 2005; Calver et al., 2007; Gordon et al., 2010).

95 A new device, the Birdsbesafe® cat collar cover (hereafter BBS) marketed by Birdsbesafe LLC, Duxbury, Vermont, USA, exploits songbirds' colour vision (Cuthill, 2006) by giving a colourful indicator of a cat's presence (Birdsbesafe LLC, 2009). No claim is made for prey other than songbirds, nor for songbirds outside a North American context. Nevertheless, predation by pet cats is a global issue, so it is of interest whether the BBS is effective outside North America. Moreover, many
100 herpetofauna (amphibians and reptiles) have excellent colour vision (Vorobyev, 2004; Olsson et al., 2013) and could be warned. Thus the BBS could be useful where owners wish their cats to hunt mammalian pests only, because many non-primate placental mammals have limited colour vision (Vorobyev, 2004).

Using an experimental approach, this study used suburban cats in Australia to evaluate: 1) Does the
105 BBS reduce the number of prey brought home? 2) Does the number of prey brought home vary by BBS colour? 3) Does the number of prey brought home differ by taxa according to their colour vision?, and 4) Do cats bring home fewer prey following treatment with the BBS (is there a lasting inhibition after a period without the reinforcement of a successful hunt)? Additionally, given the importance of owners' behaviour in the success of any anti-predation measure, we interviewed
110 owners on their experiences using the BBS.

2 Materials and methods

In common with all other published studies of the effectiveness of predation deterrents, our dependent variable was the number of prey brought home by cats when wearing or not wearing the BBS. This is not the same as monitoring all hunting behaviour or all prey captures. It cannot account
115 for the possibility that some prey are killed and left, or consumed. We also focused our attention on vertebrates and did not ask owners to note invertebrate prey brought home.

2.1 The Birdsafe® cat collar cover

The BBS is a 50cm tube of brightly coloured cloth that slips over a standard cat safety collar to appear as a brightly coloured 'ruff' or flared-out encircling cloth 'clown collar' about 5cm wide (Fig. 120 1a). Between 2012 and 2013, the design changed to include a silver retroreflective strip around the outer edge. The safety collar with the BBS can be worn constantly or fitted when the cat is allowed outdoors. Multiple colourful prints are available, and designs change with customer feedback on perceived effectiveness. Striped patterns of various bright colours predominate in the current range. The current iteration of the BBS is patent pending in the USA and is similarly protected in a further 28 125 countries.

2.2 Study area

The study ran from October 2012 until February 2013 and from October 2013 until January 2014 (southern hemisphere spring to summer) in outer suburbs of Perth, Western Australia (31.95° S, 115.85° E) and including the nearby City of Mandurah and the towns of Harvey, Dwellingup and 130 Manjimup. The mediterranean climate of the region, with fine, dry weather extending from late spring to early autumn, encourages outdoor husbandry of cats. In the second year, one participant was from Port Hedland (20.31° S, 118.60° E) in the north of Western Australia, which possesses a semi-arid climate and is warm year-round.

2.3 First year of study (2012-2013) - testing effectiveness of red, yellow and rainbow BBS

135 In the first year we tested all hypotheses in a trial involving three prints: yellow print with red, fuchsia and white abstract design, red-white paisley print, or a rainbow of stripes of red, yellow, grey, white or fuchsia; hereafter called yellow, red and rainbow respectively (Fig. 1b). Forty-four volunteers were accepted from respondents to advertisements in local newspapers seeking owners of cats that were active hunters. Respondents whose cats did not bring home on average one prey 140 every fortnight were declined. Sixty-one cats began the study but owners withdrew eight before it ended, so 53 cats (33 females and 20 males; 96% desexed) from 39 households completed the study.

The results from multiple cats in the same household were combined because prey kills could not be ascribed confidently to a specific cat, resulting in a final sample size of 39. Therefore the experimental unit for the study is the household rather than the individual cat and no correction was made to the data for any household where more than one cat was present (that is, we did not divide the number of prey brought home by the number of cats in the household).

To assess the effect of BBS colour, cats were assigned randomly to a colour group: red, yellow or rainbow. To assess the permanence of any behavioural change, half of the cats were monitored with the BBS fitted for 3 weeks followed by 3 weeks without the BBS, while the others were monitored for 3 weeks without the BBS followed by 3 weeks with it. This ensured that all cats spent a period with and without the device, while allowing for possible effects of the sequence of treatments or changes in prey availability over time. We fitted new cloth safety collars with break-away buckles designed to release if the cat was snagged underneath the BBS unless the owner preferred another collar. Cats that had not worn a collar previously were given at least 2 days to adjust to wearing a collar before the BBS was fitted. Multiple cats in the same household had synchronous treatments. All collars and BBS were fitted initially during a home visit, in which the importance of correct fit for safety was explained to owners.

Owners collected corpses brought home by their cats and reported any instances where live prey were seen to escape. Owners were instructed to contact the investigators if prey were injured and required veterinary care, but no such referrals were made. Prey bodies were identified to species by staff at the Western Australian Museum. Most prey released after owner intervention were classed as mammals, birds or herpetofauna unless the owner provided a clear description identifying the species conclusively. They were counted as captured prey because they may well have died from shock, injury or infection. We excluded any obviously nestling birds from analysis because they would not have any opportunity to escape from a cat irrespective of whether or not it was wearing a BBS. Any household that completed the study, but where no prey at all were brought home, was

also excluded. This eliminated any bias that may have been caused by including cats that did not bring home prey in the study. After the study, owners participated in a short interview assessing their reasons for volunteering and their experiences with the BBS. The interview comprised eight
170 consistent, open-ended questions, pre-approved as part of the Human Ethics Permit, which sought to obtain owners' responses in their own words (Appendix 1).

2.4 Second year of study (2013-2014) - testing effectiveness of rainbow BBS and colour vision

Preliminary analysis of data from the first year of the study indicated that cats wearing the rainbow
175 BBS showed the greatest proportional reduction in the numbers of birds and lizards brought home, so the second year assessed the rainbow BBS only. The hypotheses that the BBS reduces prey brought home, that prey brought home differ by taxa according to their vision (colour or not), and that cats bring home fewer prey following treatment with collars were relevant.

Seventy-one cats began the study, none of which had been involved before. Ten did not finish, so 61
180 (32 males and 29 females; 100% desexed) completed. Results from multiple cats in the same household were combined, again with no correction for the number of cats, resulting in a final sample size of 43 (we did not divide the prey brought home by the number of cats in a household). Otherwise, the methods for this study were identical to the first year.

2.5 Statistical analysis

185 We used generalised linear mixed effects models in R to evaluate to evaluate effect of the BBS, its colour and order of application on the numbers of birds, herpetofauna and mammals brought home and any lasting reductions in prey brought home. Our first analysis focused on the effects of BBS colour, prey taxon and order of BBS application using data from the first year of the study. Prey brought home were recorded by individual cat-household (hereafter simply called cat), prey type
190 (bird, herpetofauna, mammal), and BBS status (on/off), yielding six possible combinations per cat. We did not consider the sex or the age of the cats given that cats were allocated randomly to

experimental treatments and that multiple cats in the same household were treated as one unit.

This approach permitted evaluation of change in prey brought home within cat; as expected,

substantial heterogeneity in prey brought home existed between cats, rendering group-wide

195 averages of little value.

We fitted a model containing a random effect of cat and fixed effects for BBS on/off, order of BBS

application, BBS colour (red, rainbow and yellow), prey taxon (mammals, birds, herpetofauna), as

well as interactions of prey and colour. Capture data were strongly right skewed (reflecting

heterogeneity across individual cats), so we evaluated both normal and Poisson distributions.

200 Analysis outcomes were the same with both distributions but with substantially better fit using a

Poisson distribution, which we report. We then examined the full model for fit and any violations of

standard assumptions following suggestions of Zuur et al. (2009).

To evaluate the effect of BBS colour we set our statistical contrasts as the effect of BBS colour

relative to yellow (given that red and rainbow were more similar) and to evaluate the effect of prey

205 taxon we set capture rates relative to mammals, which is the group with the poorest colour vision

(Vorobyev, 2004) (and reductions in mammals brought home were not claimed for the BBS).

We report graphical summaries as changes in prey brought home with BBS (on vs off) and statistical

effects as changes in prey brought home overall (including an effect of BBS being worn). Estimates in

the model are reported with their standard errors and changes in prey brought home with 95%

210 confidence limits where lack of overlap with zero was interpreted as evidence of a significant effect.

Our second analysis used data for cats wearing the rainbow BBS in the first year of the study and

also cats wearing the rainbow BBS in the second year of the study. Year (first or second year), order

of BBS application (BBS applied first versus BBS applied second) and colour vision (birds and

herpetofauna combined versus mammals) were included as factors. No contrasts were needed in

215 this analysis because each of the categorical factors was binary.

2.6 Owner interviews

At the end of each year of the study, owners were interviewed regarding their experiences with the BBS, the response of their cat, and the likelihood that they would continue to use the BBS (Appendix 1). Owners' answers to the interview questions are described in text.

220 2.7 Ethical considerations

The work was covered by Murdoch University Animal Ethics Committee permit R2469/12 and Human Ethics Committee permit 2012/056. There are no conflicts of interest associated with this publication. As part of the requirements of the Human Ethics permit, all participating owners received a short report summarising the results shortly after the conclusion of the study. All owner
225 interviews were completed before the report was distributed.

3 Results

3.1 Features of cats and their husbandry

The mean age of cats that completed the trial in Year 1 was 4.4 ± 0.5 (SE) years and in Year 2 3.9 ± 0.4 years. In each year 60% were kept inside at night but were allowed out during the day, while the
230 remaining 40% could go in and out when they pleased. All the cats were desexed except for two cats in the first year. Eighteen cats were withdrawn across the entire study for a diverse range of reasons (Table 1).

3.2 Effectiveness of colour treatments in the first year

Five cats were excluded from analysis because they brought home no prey at all over the entire
235 period of the study. The others brought home 68 birds (excluding five fledglings) from at least 15 species (13 native), 49 herpetofauna from at least seven species (all native) and 77 mammals from four species (one native) (Table 2). Almost all the herpetofauna were reptiles, with only one unidentified frog brought home (the owner did not keep the body).

On average, the cats that brought home at least one prey over the trial brought home 1.04 ± 0.21
240 birds, 1.18 ± 0.17 mammals and 0.72 ± 0.20 herpetofauna (mean \pm SE). Although most of the prey

species were native animals, the majority of individual mammals brought home comprised non-native mammal species (house mouse *Mus musculus* and black rat *Rattus rattus*). Only one species, the southern brown bandicoot *Isodon obesulus fusciventer*, was of conservation concern (rated nationally as Least Concern (Woinarski et al., 2014), and as Priority Five (Conservation Dependent) in Western Australia (Department of Parks and Wildlife 2013)).

Of the total amount of prey brought home across the 6 week period, the cats in the red treatment brought home only 31% of mammal prey, 41% of bird prey and 36% of herpetofauna prey whilst wearing the BBS. The cats in the rainbow treatment brought home 50%, 28% and 4% respectively, while for the cats in the yellow treatment they were 58%, 54% and 20% respectively (Table 3).

Combining all prey groups, there was a reduction of 37% (95% CL 29% - 46%) in the prey brought home by cats when wearing the BBS. Considering only the taxa with good colour vision (birds and herpetofauna), the reduction caused by wearing the BBS was 54% (95% CL 43% - 64%).

The full generalised linear mixed effects model showed that the order in which cats wore the BBS did not influence prey brought home (effect= 0.09, Z=0.4, P=0.71). Thus the effect of order of application was excluded from the reduced model with all other effects. Across all taxa cats wearing the BBS brought home significantly fewer prey (Table 4a, Fig. 2). Fewer herpetofauna were brought home than birds or mammals. Across all prey taxa, rainbow and red BBS had similar effects to yellow (Table 4a). When prey taxon and BBS colour were considered together, cats wearing the rainbow BBS or the red BBS brought home fewer birds relative to mammals wearing the yellow BBS (Table 4a, Fig. 2).

3.3 Effectiveness of treatments using rainbow BBS in both years

Four cats in the Year 2 sample were excluded from analysis because they brought home no prey at all over the entire period of the study. The others brought home 40 birds (excluding three fledglings) from at least nine species (seven native), 57 herpetofauna from at least eight species (all native) and

265 100 mammals from five species (two native) (Table 2). On average, the cats that brought home prey brought home 0.51 ± 0.09 birds, 1.28 ± 0.18 mammals and 0.73 ± 0.14 herpetofauna (mean \pm SE).

Of the total amount of prey brought home across the 6 week period, cats in Year 2 brought home 49% of mammal prey, 40% of bird prey and 46% of herpetofauna prey whilst wearing the rainbow BBS (Table 3). Combining all prey groups, there was a reduction of 14% (95% CL 9% - 22%) in the
270 prey brought home by cats when wearing the BBS. Considering only the taxa with good colour vision, the reduction caused by wearing the BBS was 24% (95% CL 14% - 36%).

Generalised linear mixed effects models using data from both years for cats wearing the rainbow BBS found a significant reduction in the number of prey with colour vision (birds and herpetofauna) brought home relative to mammals with poor colour vision (effect=-0.72, Z=5.9, P<0.001, Table 4b,
275 Fig. 3). The order in which cats wore the BBS was not significant in its own right (effect=0.03, Z=0.16, P=0.0.88) nor in an interaction with another variable, nor was the effect of year (effect=-0.18, Z=0.9, P=0.38).

3.4 Cat behaviour, prey behaviour, owner interviews and animal welfare issues

3.4.1 Cat Behaviour

280 Over both years of the study 79% of owners reported that their cat(s) had no problem adjusting to the BBS and another 17% said that their cat(s) adjusted within 2 days. One cat took 10 days to adjust and two cats did not adjust to the BBS during the trial. One cat was withdrawn from the study because her owner felt she was not adjusting to the BBS. Although her cat was not bothered by the BBS, one owner in Year 1 said that the pet dogs in the household were upset by the cat wearing the
285 BBS and barked at him more. Owners were not prompted to assess specific behaviours in deciding whether or not their cats adjusted to the BBS, but made subjective judgements of their own.

Sixteen owners (ca.20%) reported that their cats' behaviour patterns changed while wearing the BBS. In Year 1, two owners reported their cats stayed out more and six owners from Year 1 and eight

from Year 2 reported that their cats stayed closer to home/came in earlier for food. The owners
290 reported that 14 of the cats that came in earlier ate more than normal and were more affectionate.
Of these, five cats that wore the BBS for the first half of the trial reverted to their previous behaviour
when the BBS was removed, while the others continued to be more affectionate. However, some
owners changed their answer to this question when asked if their cats' behaviour had changed once
they were given an example of what the behaviour change might be.

295 3.4.2 Prey Behaviour

Several owners mentioned that even though their cat had not brought home any birds during the
study, birds surrounding their house tended to stay in the trees while the cat was wearing the BBS
and give their warning calls earlier. When the BBS was removed birds often stayed on the ground
even when the cat was close. One owner from Year 2 withdrew her cat after her pet cockatoo
300 became distressed by the cat wearing the BBS and would not stop screeching. In contrast, two
owners said their cats brought home birds for the first time ever while wearing the yellow BBS in
Year 1. One owner reported seeing lizards freezing when the cat approached wearing the BBS, but
this did not occur when the BBS was removed.

3.4.3 Owner Interviews

305 Of the owners whose cats completed the trial using the red BBS, seven (64%) believed that it
worked, one (9%) did not believe that it worked and 27% were unsure. Of the owners whose cats
completed the trial using the rainbow BBS in either year, 31 (48%) believed that it worked, 11 (17%)
did not believe that it worked and the remaining 35% were unsure. Amongst owners whose cats
trialled the yellow BBS, six (46%) of owners believed that the yellow BBS worked and six (46%) did
310 not believe that it worked and one owner was unsure. These were subjective judgements by the
owners based on their own experiences and they were not prompted to consider data from their
own cat or from the study overall. Despite this, 77% of all owners over both years plan to continue
using the BBS. The two most common reasons for not continuing to use the BBS were that the cat

did not bring home many (if any) birds and therefore the owners felt it was not relevant to them
315 (five owners), and that some owners did not like the look of the BBS on their cat (five owners).
Eighty per cent of owners over both years felt that a retail price of \$15 was appropriate but the
remaining 20% felt that it was too expensive.

Two owners commented that they liked that the BBS does not make a noise, especially one owner
who said that her cat's bell was constantly waking her newborn baby. In contrast, several owners
320 wished to make the BBS more effective by adding bells as an auditory warning to all prey, including
mammals. Two owners said they liked the bright colours and the retroreflective strip around the
edge of the BBS to make the cats more visible to cars at night.

3.4.4 Animal Welfare Issues

Two cats from different households suffered from dermatitis attributed to the BBS. One had it very
325 mildly and continued in the study but the other was withdrawn and needed minor veterinary
treatment.

Two cats (one from each year) caught a paw through their collars. One suffered no ill effects, but the
other caught its paw repeatedly and was withdrawn from the study. One cat caught the safety collar
(not while wearing the BBS) in her mouth, ran away and was presumed to be hit by a car. One owner
330 said that the BBS knotted her cat's fur under the collar and three owners said their cats were
bothered when grooming.

4 Discussion

4.1 Prey captures

Studies of pet cats' hunting behaviour show great individual variation and opportunism in their
335 hunting behaviour (e.g. Barratt, 1997, 1988; Woods et al., 2003; Loyd et al., 2013). The cats in our
study were similar, varying in the number and type of prey brought home. The preponderance of
introduced rodents was expected, probably reflecting their availability in the environment and the

hunting skills of cats (Fitzgerald and Turner, 2000; Meachen-Samuels and van Valkenburgh, 2009a,b; Bradshaw et al., 2012). The frequency of herpetofauna brought home reflected the availability of
340 lizards in Perth over spring and summer. The birds brought home were mainly nectarivorous
honeyeaters and wattlebirds or granivorous doves, pigeons or parrots, reflecting their abundance in
suburban gardens. Given that the cats studied were a sample of known hunters, it is inappropriate
to extrapolate from these data to estimate their impact on wildlife in Perth, although the results do
indicate the prey species at risk. A full assessment of impacts on prey populations would also require
345 demographic data on those populations.

4.2 Effectiveness of the BBS

Not all BBS colours were equally effective, but the rainbow BBS did lead to a statistically significant
reduction in the numbers of prey with colour vision (birds and herpetofauna) brought home. This
was driven substantially by reductions in herpetofauna prey, especially in Year 1, plus smaller
350 reductions in numbers of birds brought home. Anecdotal reports from some owners of birds
responding differently to the same cat with and without a BBS and of a caged bird being distressed
at the approach of a cat wearing a BBS indicate that at least some birds detect and respond to the
BBS. We are unaware of experimental evidence that other anti-predation devices significantly
reduce the number of herpetofauna brought home (e.g. Ruxton et al., 2002; Woods et al., 2003;
355 Nelson et al., 2005; Calver et al., 2007). For mammals, which comprised the majority of prey, the
numbers brought home by cats when wearing or not wearing the BBS were similar. While there was
no evidence that the number of prey brought home remains depressed if a cat ceases to wear a BBS,
this hypothesis is worth further investigation. Training a cat to abandon hunting may be more
attractive to owners than persisting with a device, and there is evidence of a decline in prey brought
360 home when the reinforcement of successful prey capture was reduced (Calver et al., 2007). The
effectiveness of the BBS in reducing prey brought home in a given situation will likely be driven by
characteristics of the local prey community, the husbandry practices of owners, characteristics of

cats, and the local prevalence of bird feeders. The most robust assessment of its effectiveness in reducing the number of prey brought home would come from a meta-analysis of multiple trials.

365 Regarding characteristics of the prey community, the lack of reduction in mammals brought home probably arises from a combination of their nocturnal habits and the prevalence of dichromatic vision with limited colour vision in non-primate placentals (Vorobyev, 2004). However, the Australian marsupials the southern brown bandicoot (a prey item in this study), the quokka *Setonix brachyurus*, the honey possum *Tarsipes rostratus* and the fat-tailed dunnart *Sminthopsis*
370 *crassicaudata* have trichromatic vision (Ebeling et al., 2010) and should, under the right conditions, discriminate colours in a BBS. Similarly, herpetofauna may be mainly diurnal or nocturnal, with nocturnal species unlikely to detect a cat wearing a BBS by colour, despite the prevalence of trichromatic or tetrachromatic colour vision in herpetofauna (Vorobyev, 2004). Birds have predominantly tetrachromatic vision, with the fourth colour cone using UV-sensitive or violet-sensitive (UVS) pigments (Cuthill, 2006). The ratios of different cone types vary between species
375 (Hart, 2001; Cuthill, 2006; Ödeen and Håstad, 2010), so different species may perceive the BBS differently and its effectiveness may vary. Irrespective of vision type, all birds are vulnerable at their roosts, so whether or not a cat is confined at night is important in the efficacy of the BBS. Although 60% of owners kept their cats indoors at night in this study, many of these cats were still outside at
380 dawn and dusk when visibility is low, possibly reducing the effectiveness of the BBS. The BBS may also vary in effectiveness with factors such as the coat length of the cat.

Bird feeders attract birds (Daniels and Kirkpatrick, 2006; Davies et al., 2009; Shochat et al., 2010; MacGregor-Fors and Schondube, 2011) and could increase the opportunity to demonstrate reductions in prey brought home. However, in Australia, bird feeders are discouraged by
385 government and conservation groups because of disease and attracting exotic species (Australian Wildlife Society, 2014; NSW Government, 2014). In the USA, where bird feeding is popular and

encouraged by government agencies (U.S. Fish & Wildlife Service, 2001), there will be more opportunity for cats to hunt birds and a study may give stronger findings.

Furthermore, collar-mounted video cameras confirm that pet cats bring home approximately 23% of their prey (Loyd et al., 2013). Using collar-mounted cameras in conjunction with a BBS would be
390 necessary to discount (i) that fitting a BBS simply discourages a cat from bringing prey home, or (ii) the BBS might reduce the number of prey killed that are never brought home (which would not be apparent using the methodology in our study). Sixteen owners reported changes in their cats' behaviour with 14 of these described as coming home earlier, eating more food and becoming more
395 affectionate while wearing the BBS. Perhaps these cats usually eat their prey in situ and, unable to supplement their diet through hunting, they came home earlier.

Lastly, the BBS was developed to reduce predation on songbirds in a North American context. Thus the data reported here cover a dissimilar context and may not reflect the situation in North America. The cats in the study were volunteered as known hunters, but not necessarily accomplished bird-
400 killers. Furthermore, given that the BBS product range is constantly evolving, the results of this study may not reflect the effectiveness of current designs.

4.3 Welfare considerations and cat behaviour

Minor problems with cats catching paws or teeth in collars are common (between 27% and 62% of
405 two groups of owners sampled had experienced these problems over a lifetime of pet ownership), while serious injury requiring veterinary attention was rarer (3% and 6% respectively for the same groups) (Calver et al., 2013). Problems are most likely if a collar frays or is fitted loosely, so regular inspection is important (Lord et al., 2010; Calver et al., 2013). In this study, problems arose from loose collars. The cases of dermatitis attributed to the BBS were unusual. Two cats did not adjust to
410 the BBS at all, a problem that can occur with other predator deterrents (Calver et al., 2007).

Whether a cat is perceived to adjust is a subjective assessment by the owner. The current packaging for BBS products advises owners to fit the BBS when the cat is inside and to monitor closely.

4.4 Implications for wildlife conservation

Even though pet cats may not be the primary source of wildlife decline in urban areas, they do hunt wildlife at levels unsustainable for some species in some places (Lepczyk et al., 2004; van Heezik et al., 2010; Thomas et al., 2012). While several deterrent devices reduce prey brought home (Ruxton et al., 2002; Woods et al., 2003; Nelson et al., 2005; Calver et al., 2007), the BBS uniquely reduces numbers of birds and herpetofauna brought home but not mammals. It is suitable for farmers who want their cats to catch rodents but not other vertebrates (Coleman and Stanley, 1993), as well as in New Zealand where all mammals except bats are exotic (Gordon et al., 2010) but endemic birds and herpetofauna are at risk of predation by cats (Veitch, 2001). If rats and mice are still hunted, birds and herpetofauna may benefit from reduced rodent predation (Fitzgerald and Turner, 2000; Dickman, 2009; Hansen, 2010). However, the current study gives no indication about predation by pet cats on large invertebrates, which may be significant in invertebrate population ecology (Wehi et al., 2011) or conservation (Watts et al., 2011). This may qualify comments about the value of the BBS in New Zealand, where large invertebrates such as wetas (several insect species within the orthopteran sub-order Ensifera) are a conservation concern (Watts and Thornburrow, 2009).

Almost half of the study cats brought home at least one lizard and, based on owners' observations, lizard predation goes predominantly unnoticed. However, cat predation may suppress lizard populations (Arnaud et al., 1993) and in one case a single pet cat caused a local extirpation of the lizard *Ctenotus fallens* on a suburban Perth property (Bamford and Calver, 2012). This is particularly important in Australia, where the reptile fauna is diverse with many endemic species (Edwards et al., 2012).

However, simply reducing predation does not mitigate all potential impacts of pet cats on wildlife. Birds may experience life-history changes such as a reduction in fecundity when they perceive

predation risk as high, even if predation is low (Beckerman et al., 2007). Bonnington et al. (2013) found that parental provisioning rates in birds were reduced by one third following exposure to a cat model, which could reduce nestling growth rates by 40%. Furthermore, the presence of the cat model for only 15 min at the nest significantly increased the chances of nest predation over the next 440 24 h by corvids detecting increases in alarm calls.

Free-roaming pet cats have greater risk of contracting the parasite *Toxoplasma gondii* by eating infected small mammals (Dubbey and Lappin, 2012). While infected cats are asymptomatic, intermediate hosts may suffer blindness, impaired walking, calcification of the heart, miscarriage and stillbirth (Tenter et al., 2000; Torrey and Yolken, 2003). *T. gondii* is often fatal for Australian 445 marsupials because of their recent exposure (Eymann et al., 2006). Although some anti-predator devices may reduce the risk of *T. gondii* infection to pet cats through reductions in mammal capture, the BBS does not reduce predation on mammals and will not reduce infection risk.

The best solution for reducing impacts is by restricting cats to their owner's property (Perry, 1999). This also benefits cats' welfare by reducing fighting and road accidents (Rochlitz, 2003a,b, 2004). 450 However, many owners object to keeping their cats on their properties at all times (Grayson et al., 2002; Lilith et al., 2006; Thomas et al., 2012) so deterrent devices provide an alternative. Wildlife conservation in urban areas will also require attention to other threats including high residential densities, failure to design wildlife-friendly gardens or parks, poor conservation of remnant native vegetation and traffic (Dufty, 1994; Grayson et al., 2007).

455 Unowned cats roaming in cities, sometimes supported by people feeding them, require alternative approaches (Lepczyk et al., 2010; Farnworth et al., 2011; Aguilar and Farnworth, 2013). The recent assessment that feral cats (those forming self-sustaining populations without human support) endanger more threatened and near threatened Australian mammal taxa than any other factor (Woinarski et al., 2014) confirms that feral cats are a major problem in at least some environments 460 (Medina and Nogales, 2009; Wheeler and Priddel, 2009).

5 Conclusion

Despite uncertainty about the contribution of predation by pet cats to the population dynamics of urban wildlife, individual acts of predation are well documented. Concerned owners who do not wish to confine their cats may consider a collar-worn predation deterrent instead. This study shows that the BBS has potential to reduce captures of vertebrates with good colour vision. It is therefore an option for owners concerned about predation on birds and lizards, but not mammals or large invertebrates.

6 Acknowledgements

We are grateful to the owners who kindly volunteered their cats for the study. BBS were purchased from BBSLLC. The proprietor, Ms Nancy Brennan, commented on an earlier version of the paper to ensure accurate description of the product and retail information, but had no involvement in study design, data collection, analysis, or the decision to submit the manuscript for publication. Dr Ric How, Ms Claire Stevenson and Mr Ron Johnstone of the Western Australian Museum identified the prey. Two anonymous reviewers gave perceptive and valuable comments on the initial submission. Birdsbesafe is a registered trademark. Catherine Hall was supported by a Murdoch University Research Studentship.

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665

FIG. CAPTIONS

Fig. 1a: Cat wearing the rainbow Birdsbesafe® cat collar. (This is to appear in colour online and in print).

670 Fig. 1b: Colours Tested During the Trial; Red, Yellow, Rainbow. (This is to appear in colour online and in print).

Fig. 2. Means (\pm 95% CI) for the change in prey brought home for birds, herpetofauna and mammals for cats wearing three different colours of BBS in Year 1.

675 Fig. 3. Means (\pm 95% CL) for the change in prey brought home for birds, herpetofauna, mammals and prey with full colour vision (herpetofauna and birds combined) and prey with limited colour vision (mammals) for cats wearing the rainbow of BBS in Years 1 and 2 combined.

Table 1: Owners reasons for withdrawing their cats from the study

Year	No. of Cats	Reason
Year 1	1	Moderate dermatitis attributed to the BBS
Year 1	1	Owner personal issues
Year 1	2 (same household)	Owner found BBS to be ineffective against mammals and she did not like her two cats bringing mice into the house and wanted to deter their hunting behaviour more generally
Year 1	1	Owner concluded that the BBS was not effective for her cat and it was rehomed
Year 1	1	Owner did not like the appearance of the BBS and her cat was not a regular hunter
Year 1	2 (same household)	One cat caught its safety collar (not BBS) in its mouth and in her distress, ran away and was presumed to be hit by a car. The other cat in the household was then withdrawn from the study.
Year 2	1	The cat would not adjust to the BBS
Year 2	1	Pet bird in household became too distressed by cat walking past wearing BBS
Year 2	1	Owner lived in a very hot climate and decided that the device would make her cat too uncomfortable
Year 2	2 (same household)	The owner had three cats, two of which were being targeted by a local feral cat and she felt that the BBS was a hindrance in a fight although she was happy to leave her third cat in the trial
Year 2	1	Owner could not be contacted
Year 2	1	One owner chose not to continue because he did not want his cat to be outside without any device that would stop it catching wildlife
Year 2	1	Cat was constantly catching his front leg through the collar
Year 2	2 (separate households)	Cat continually lost collars and BBS

680 Table 2 - List of birds, mammals and herpetofauna brought home by cats during the six week trials in Year 1 and Year 2 and which could be identified to species level. Common and scientific names are consistent with Clayton et al. (2006).

Prey Category	Common Name	Scientific Name	Years (numbers brought home)
Bird			
	Button-quail	Turnix sp. ^b	Year 1 (1)
	Laughing Turtle-Dove	Streptopelia senegalensis	Years 1 & 2 (3, 1)
	Spotted Turtle-Dove	Streptopelia chinensis	Years 1 & 2 (4, 3)
	Common Bronzewing	Phaps chalcoptera ^b	Years 1 & 2 (2, 2)
	Crested Pigeon	Ocyphaps lophotes ^b	Year 1 (2)
	Australian Ringneck (Twenty-eight Parrot)	Barnardius zonarius ^b	Year 1 (2)
	Red-capped Parrot	Purpureicephalus spurius ^b	Year 2 (1)
	White-browed Scrubwren	Sericornis frontalis ^b	Year 1 (2)
	Brown Honeyeater	Lichmera indistincta ^b	Years 1 & 2 (4, 2)
	Singing Honeyeater	Lichenostomus virescens ^b	Years 1 & 2 (2, 2)
	New Holland Honeyeater	Phylidonyris novaehollandiae ^b	Years 1 & 2 (2, 5)
	Red Wattlebird	Anthochaera carunculata ^b	Years 1 & 2 (1, 1)
	Willy Wagtail	Rhipidura leucophrys ^b	Year 1 (1)
	Magpie Lark	Grallina cyanoleuca ^b	Year 1 (2)
	Australian Magpie	Gymnorhina tibicen ^b	Year 1 (1)
	Grey-breasted White-eye (Silvereye)	Zostergis lateralis ^b	Years 1 & 2 (4, 1)
Reptile			
	Marble Gecko	Christinus marmoratus ^b	Years 1 & 2 (1, 5)
	Blind Snake	Ramphotyphlops australis ^b	Year 2 (1)
	Fence Skink	Cryptoblepharus buchananii ^b	Years 1 & 2 (4, 1)
	Two-toed Earless Skink	Hemiergis quadrilineata ^b	Year 2 (1)

	Hemiergis initialis ^b	Year 1 (2)
Western Limestone Ctenotus	Ctenotus australis ^b	Year 2 (1)
Common Dwarf Skink	Menetia greyii ^b	Year 2 (1)
Tree Dtella	Gehyra variegata ^b	Years 1 & 2 (1, 4)
Western Three-lined Skink	Acritoscincus trilineata ^b	Years 1 & 2 (1, 2)
Bearded Dragon	Pogona minor ^b	Year 1 (3)
King Skink	Ergenia kingii ^b	Year 1 (1)
Mammal		
Black Rat	Rattus rattus	Years 1 & 2 (16, 23)
Lesser Long-eared Bat	Nyctophylus geoffroyi ^b	Year 2 (3)
House Mouse	Mus musculus	Years 1 & 2 (20, 13)
Rabbit	Oryctolagus cuniculus	Years 1 & 2 (5, 2)
Southern Brown Bandicoot	Isodon obesulus fusciventer ^{a,b}	Years 1 & 2 (8, 6)

a Species of conservation concern

b Native species

Accepted

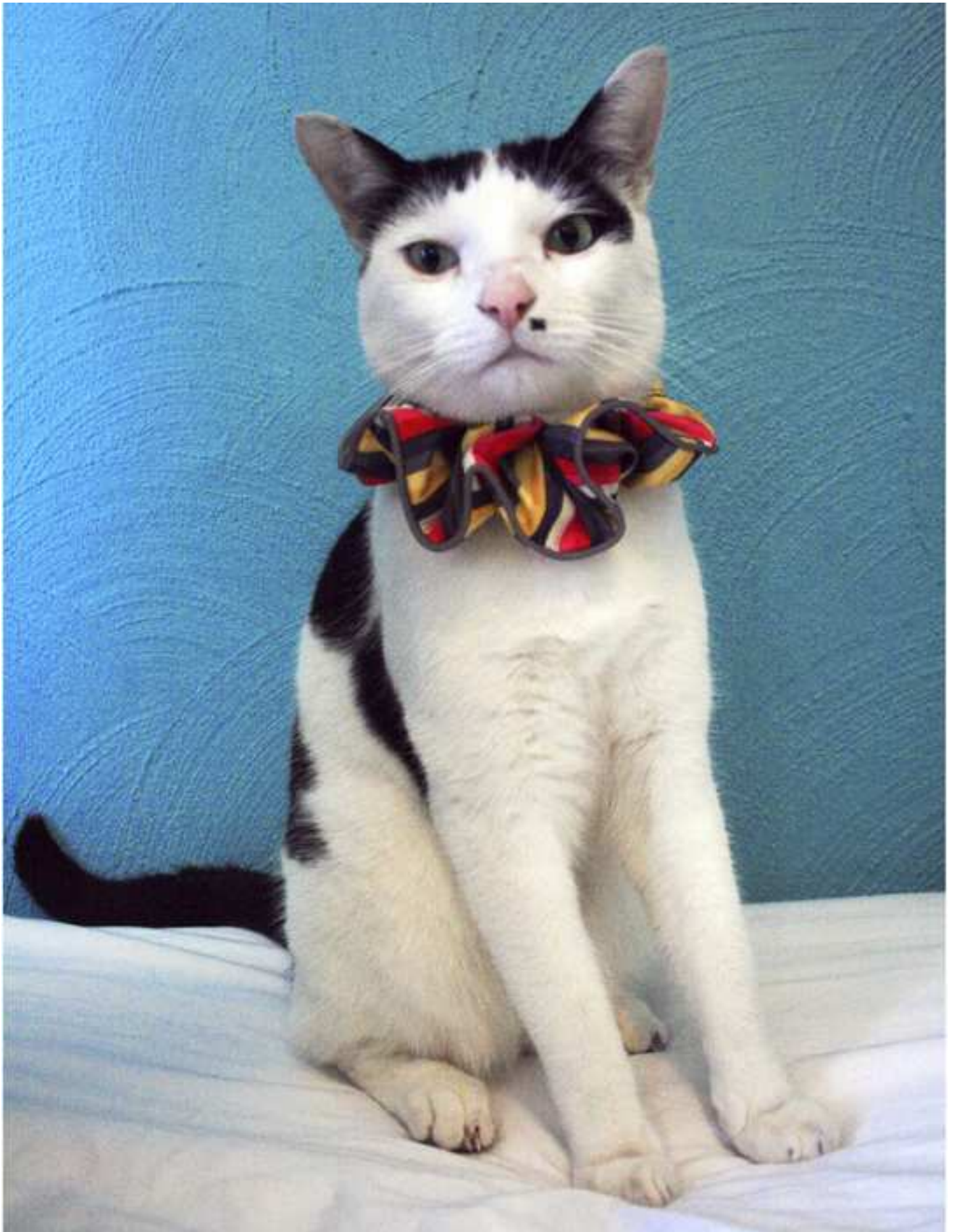
685 Table 3: Total number of prey brought home by cats in each treatment group in each year. The number of cats (with cats in multiple-cat households counted as one cat and all prey summed) bringing home prey is given in parentheses.

Treatment	Year	Prey	Application	
			Treatment On	Treatment Off
Red	2012	Mammal	4 (3)	9 (5)
		Bird	13 (5)	19 (7)
		Herpetofauna	5 (4)	9 (5)
Yellow	2012	Mammal	14 (7)	10 (6)
		Bird	12 (6)	10 (4)
		Herpetofauna	2 (2)	8 (2)
Rainbow	2012	Mammal	20 (8)	20 (10)
		Bird	4 (3)	10 (6)
		Herpetofauna	1 (1)	24 (5)
Rainbow	2013	Mammal	49 (19)	51 (23)
		Bird	16 (11)	24 (15)
		Herpetofauna	26 (14)	31 (15)

690 Table 4: (a) Estimates from top model examining effects of wearing a BBS, BBS colour and prey type
 on prey brought home by pet cats, after removing insignificant effects from the complete model of
 all effects and interactions. Effects of prey taxon are assessed relative to captures of mammal prey
 and interaction effects of prey taxon x BBS colour are assessed relative to captures of mammals by
 cats wearing a yellow BBS. (b) Estimates from top model examining effects of wearing a rainbow BBS
 and prey colour vision (good colour vision, birds and herpetofauna; poor colour vision, mammals).

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Term	Estimate	SE	Z-value	P-value
(a)				
BBS On	-0.46	0.15	3.1	0.002
Bird	-0.09	0.30	0.3	0.77
Herpetofauna	-0.87	0.38	2.3	0.02
Rainbow	0.32	0.34	1.0	0.34
Red	-0.58	0.42	1.4	0.16
Rainbow*Bird	-0.96	0.43	2.2	0.03
Rainbow*Herpetofauna	0.41	0.46	0.9	0.38
Red*Bird	0.99	0.45	2.2	0.03
Red*Herpetofauna	0.95	0.54	1.7	0.08
(b)				
BBS On	-0.32	0.12	2.6	0.01
Colour Vision	-0.72	0.12	5.9	<0.001



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