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Survival rates of cat (*Felis catus*) attacked birds admitted to RSPCA wildlife centres in the UK: implications for cat owners and wildlife rehabilitators

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Abstract

Free-ranging pet cats (*Felis catus*) frequently kill wildlife but also return live prey to their owners. This raises welfare concerns if live animals released by cat owners subsequently die, since this is preventable e.g. through prompt euthanasia. To estimate the mortality rate of birds released alive by cat owners, we examined the fates of 3597 cat-attacked individuals submitted to four RSPCA wildlife centres in the UK. Individuals from 64 species were received but most cases (77%) involved just seven species commonly found in urban areas. The overall mortality rate (based on all individuals received at centres i.e. including those which perished in transport, those which were euthanased on arrival and those which were admitted for care after having been triaged) was 78%; the post-admittance mortality rate (n = 2070 birds admitted for care) was 62%. On average, individuals that perished (n = 2798) survived for 3.0 days before dying or being euthanased. Juveniles were more likely to survive to release than adults, possibly because their small size means they are less likely to receive injuries that are ultimately fatal. Extrapolating from the limited data currently available, and applying conservative estimates at each stage, we estimate that a minimum of 0.3 million birds are released annually by cat owners but subsequently die. Substantial welfare improvements could be achieved if owners were more prepared to adopt strategies to limit hunting behaviour (e.g. fitting cats with collars and bells) and if owners and rehabilitators were able to effectively identify individuals with fatal injuries. The latter will require studies that quantify the effects of identifiable physical injuries on the likelihood of survival to release, in order to establish effective triage criteria.

Keywords: animal welfare, domestic cat, depredation, *Felis catus*, hunting behaviour, wildlife rehabilitation

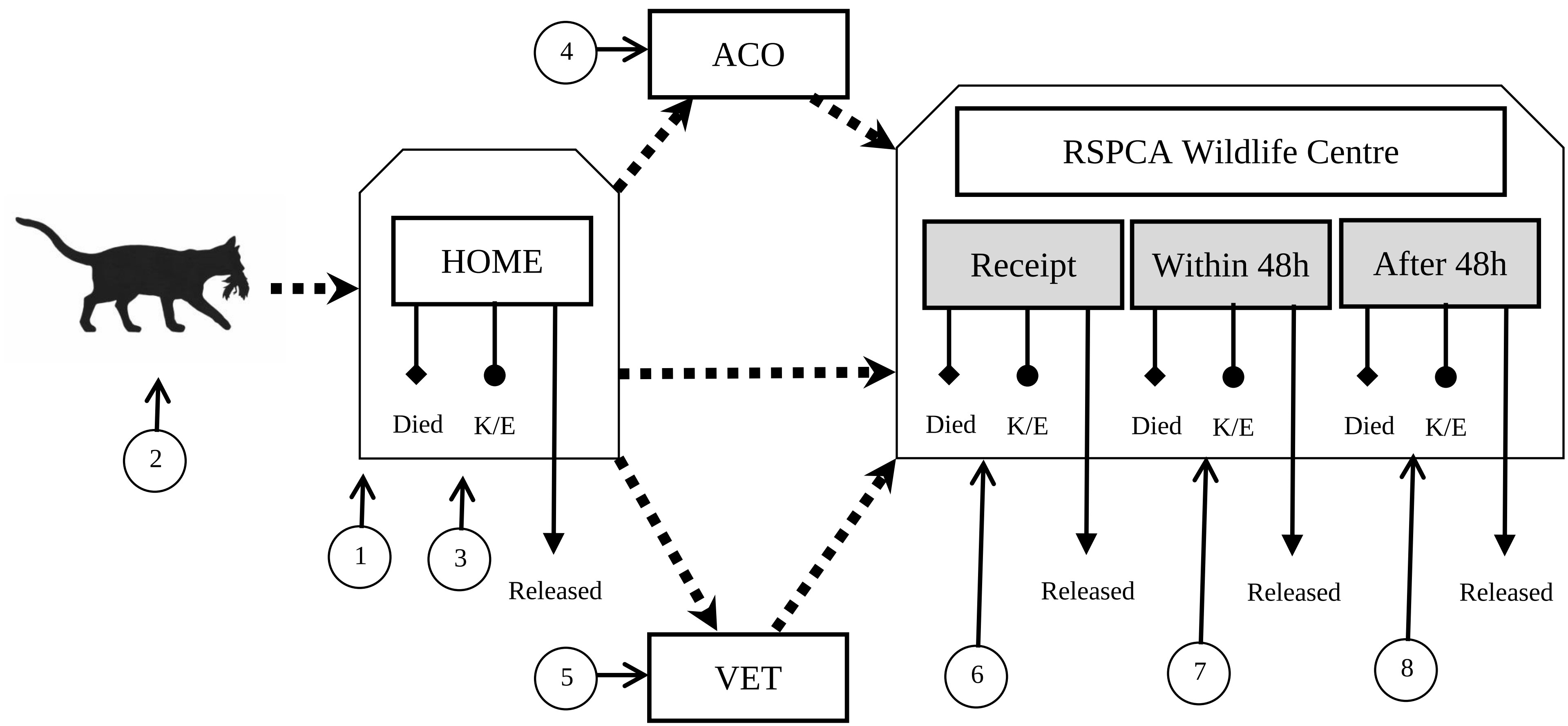
Introduction

As a companion animal and biological control agent, the domestic cat (*Felis catus*) has been introduced widely across the globe by humans, including into the UK (Long 2003). Throughout this distribution cats exhibit varying degrees of dependence on humans and this, in turn, affects how they may impact wild prey populations (International Companion Animal Management Coalition (ICAM) 2011). For example, feral cats (“unowned roaming” cats: ICAM 2011), which live independently of humans and whose numbers are linked to the availability of natural prey, have caused the extinction, extirpation and decline of a number of species (Nogales *et al* 2004; Medina *et al* 2011, 2014). Conversely, free-ranging pet cats (“owned roaming” cats: ICAM 2011) receive the majority of their nutrition from their owners, yet many individuals still catch and kill wild animals (Barrat 1997, 1998; Gillies & Clout 2003; Woods *et al* 2003; Kays & DeWan 2004; Lepczyk *et al* 2004; Morgan *et al* 2009; Balogh *et al* 2011; Tschanz *et al* 2011; Loss *et al* 2013; Woinarski *et al* 2017). Within urban areas in developed countries, pet cats are often present at very high densities (e.g. >200 km^{-2} in the UK: Sims *et al* 2008; Baker *et al* 2010), such that even low per capita predation rates could result in substantial cumulative numbers of animals killed. This has, therefore, led to increased interest in the potential impact of free-ranging pet cat populations on populations of wild prey species (Crooks & Soulé 1999; Baker *et al* 2005, 2008; Lilith *et al* 2010; van Heezik 2010; van Heezik *et al* 2010; Calver *et al* 2011; Thomas *et al* 2012).

However, pet cats do not kill every animal that they catch (Martin & Bateson 1988; Turner & Meister 1988; Fitzgerald & Turner 2000). For example, studies conducted in Bristol (Baker *et al* 2005) and Reading (Thomas *et al* 2012) in the UK recorded, respectively, that 24% and 14% of prey animals returned home by pet cats were alive, these figures equating to return rates of 0.7-2.1 live prey per cat per annum. Although extrapolations from such figures should be treated with caution because of the marked variation in patterns of predation (Baker *et al* 2008; Thomas *et al* 2012), with 10.3 million pet cats in the UK (Murray *et al* 2010), the majority of which are given access outdoors during the day and / or night (Baker *et al* 2005, 2008; Thomas *et al* 2012), these data suggest that approximately 7.2-21.6 million prey animals could be presented alive to cat owners each year.

Faced with live prey, owners have the choices of: (a) allowing the cat to kill the animal; or retrieving the animal and either (b) releasing it, (c) seeking veterinary care or (d) killing it (Figure 1). Consequently, this is a highly unusual management issue involving the impacts of an introduced predatory mammal, as there is the opportunity for cat owners, veterinary surgeons and / or wildlife rehabilitators to intervene at several possible stages (Figure 1). Such interventions could help reduce the prospect that prey are attacked per se, but also the length of time that an individual might suffer before dying. For example, banning the ownership of pet cats outright or in sensitive areas (Lilith *et al* 2010; Metsers *et al* 2010), fitting them with anti-predation devices (Ruxton *et al* 2002; Nelson *et al* 2005; Gordon *et al* 2010; Hall *et al* 2015; Willson *et al* 2015) or keeping them indoors during time periods when prey may be particularly vulnerable (Lilith *et al* 2010) would all act to reduce the likelihood of an animal being caught and injured. Alternatively, owners could take injured animals to practitioners so that they can receive pain relief, or an injured animal that is likely to die or which is not suitable for release could be killed humanely. It is this opportunity for people to intercede so readily that sets cat management apart from most other contemporary wildlife management problems.

Figure 1. Schematic representation of the timeline of events considered in this study and the points at which actions could be taken to minimize the impact of cats and to reduce levels of suffering. Live prey are returned to their owner's home. At this point the owner may: kill / euthanase the animal (K/E) or release it. Alternatively, the animal may be delivered (dashed arrows) to: (i) an RSPCA wildlife centre either by the home owner or animal collection officer (ACO) working for the RSPCA; or (ii) to a veterinary surgeon, where it is later transferred to the RSPCA. Within the RSPCA wildlife centre we consider three time periods: on receipt; within 48h of being admitted; and more than 48h after being admitted. Numbers in circles indicate points at which welfare standards could be improved: (1) the cat is prevented from leaving the house (curfews) or (2) is fitted with an anti-predation device, such as a bell, to reduce the numbers of animals attacked per se; at points (3) – (8) any animal that is fatally injured could be killed/euthanased (K/E) humanely.



Releasing an animal returned home alive would represent a welfare concern if the individual was injured and likely to die subsequently. The magnitude of this concern will be linked to the numbers of moribund individuals released and the length of time that they take to die from to their injuries. It is probably reasonable to assume that cat owners would not want to deliberately release animals that they know are going to die. However, it may also be reasonable to assume that many are not prepared to kill a wild animal because they are squeamish, they may not feel confident they could do so humanely and / or some injuries might be difficult to diagnose. For example, penetrating bite injuries may be expected to increase post-release mortality rates because of the range of bacteria present on cats' teeth (Abrahamian & Goldstein 2011) but which would require close examination of the injured animal to be identified. In addition, features of prey animals themselves, such as age and sex, may also influence their risk of being captured (Møller & Erritzøe 2000; Baker *et al* 2008; Møller *et al* 2008, 2010) and the magnitude of injuries received. For example, larger individuals could be expected to require a greater force to be subdued and also more likely to receive bite wounds whilst being carried back to the owner's house in the cat's mouth.

Quantifying the mortality rates of birds which have been caught by cats and released by their owners is, however, problematic. For example, fitting potentially injured animals with radio transmitters to definitively determine their fate could further impact their survival (sensu Murray & Fuller 2000) and, hence, their welfare. Therefore, in this study, we quantified the survival rates to release of birds admitted to wildlife centres run by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) in the UK after having been attacked by a cat. Specifically, these data were used to (i) quantify the survival rate to release of cat-attacked birds and (ii) estimate the amount of time elapsed before an individual died or was euthanased. These two measures are used respectively as proxies for (i) the survival rates of birds released alive by cat owners and (ii) the amount of time spent suffering that could be avoided if individuals that were destined to die could be identified and euthanased / killed; factors affecting the validity of these proxy measures are outlined in the Discussion. In addition, we consider (iii) how survival to release varied in relation to selected characteristics (e.g. age) for a subset of the most commonly affected species and (iv) the apparent effectiveness of triage procedures in minimising patterns of suffering of individuals received by these centres. Finally, we consider (v) the implications of these results for the welfare burden associated with cat predation in the UK.

Materials and methods

Data on admissions of birds submitted to four RSPCA wildlife centres (East Winch, Norfolk; Mallydams Wood, East Sussex; Stapeley Grange, Cheshire; West Hatch, Somerset) following an attack by a domestic cat were obtained for the period January 2005 – December 2009 inclusive. For recording purposes, animals received by RSPCA centres following an attack are allocated to one of ten causal agents; although not all of these agents can be verified conclusively in every case, those recorded as attacks by cats are likely to be accurate since these individuals would have typically been rescued by the cat's owner, or subsequent examination by a veterinary surgeon would have confirmed their injuries as being typical of a cat attack. No specific licences were required for this work as it was a retrospective analysis of data recorded by the RSPCA as part of their normal practices.

Birds were delivered to the centres either by members of the general public, members of the RSPCA (e.g. animal collection officers, inspectors) or were collected from other animal welfare organisations or veterinary surgeons. As sample sizes were small in many of these categories, the origin of people submitting birds for treatment (FINDER) was condensed to two levels for analyses: public and non-public.

On receipt at each centre (i.e. before the animal had been admitted for treatment), individuals were identified to species and aged (juvenile, adult) based on size and plumage characteristics. Where possible, animals were weighed and sexed; the latter was often not possible, however, since most species commonly admitted were not sexually dimorphic. Individuals that had died in transit were classified as dead on receipt. Animals that were still alive were triaged by centre staff and either euthanased, admitted for further treatment or released; individuals would typically be examined by a veterinary surgeon after they had been admitted. Animals admitted to the centre were initially housed in indoor cages with *ad libitum* access to food and water; after examination and / or veterinary treatment, animals were transferred to outdoor aviaries. Length of time in care (in days) was calculated by subtracting the date of receipt from the date on which the bird died, was euthanased or released: birds were released once they had good body condition, good feather condition and were able to fly (sensu Kelly *et al* 2011). For analyses, the fate of animals received was classified as died, euthanased or survived to release within each of three time periods: on receipt, <48h after admission and >48h after admission. We have not considered the effects of post-admission veterinary care (sensu Molony *et al* 2007; Kelly *et al* 2011), acknowledging that this could have the effect of increasing survival rates. Conversely, euthanasing individuals will reduce the mean time to death.

The conservation status of each species was categorised using the system developed by Eaton *et al* (2009). Red-listed species are those considered globally threatened due to a rapid decline in population size and / or range in recent years, or those that have declined historically and which have not recovered subsequently. Amber-listed species are those whose population has declined moderately in recent years or those which have made a substantial recent recovery following an historical decline; this classification also includes rare breeding species and those species in the UK which represent internationally important populations. Other species are classified as green-listed or were not assessed e.g. because they are introduced species.

Factors affecting the survival of cat-attacked birds

Binary logistic regression analysis was used to examine the effect of SPECIES, AGE (adult, juvenile), CENTRE (4 levels), YEAR (5 levels) and FINDER (member of the public versus not a member of the public) on the likelihood that an individual survived to be released after being attacked by a cat. Analysis was restricted to seven species for which there were ≥20 admissions for both adults and juveniles: blackbird (*Turdus merula*), collared dove (*Stretopelia decaocto*), feral pigeon (*Columba livia*), house sparrow (*Passer domesticus*), robin (*Erithacus ribecula*), starling (*Sturnus vulgaris*) and wood pigeon (*Columba palumbus*). Separate analyses were conducted for (i) all those individuals received at the four centres (n = 2709) and (ii) those individuals admitted for care (n = 1511). Initial starting models included all main effects and were simplified using a backwards stepwise elimination procedure: interaction terms were not included because of the small number of cases in some combinations of variables. Probability thresholds were adjusted to maximize the model's ability to assign cases into dichotomous classes and increase overall prediction success. Final model fit was assessed using Cox & Snell's and Nagelkerke's R^2 values, Hosmer-Lemeshow goodness-of-fit tests and sensitivity, specificity and overall classification indices.

All statistical analyses were conducted using SPSS version 18 (Field 2009). Sample sizes vary between analyses as not all parameters were available for all records and because some analyses were based upon sub-samples of the overall data set.

Animal welfare implications

One metric which can be used to quantify the degree of suffering encapsulated within this dataset is the amount of elapsed time before individuals died or were euthanased since this could potentially be reduced by cat owners and / or animal care professionals at many different stages (Figure 1); it also represents the potential amount of time an injured individual might be expected to suffer before dying if released by a cat owner (excluding, of course, the amount of time before the cat returns to its home with its prey). To arrive at a centre, individuals would first have had to be transferred from the owner's home. In basic terms, injured birds will be delivered to RSPCA wildlife centres in one of two ways: (a) they are taken by the cat owner (public FINDER); or (b) he / she contacts the RSPCA who then arrange for the bird to be collected and then delivered (non-public FINDER).

At present, there are no data currently available on the amount of time taken from an owner discovering an injured bird that his/her cat has delivered to its arrival at a wildlife centre. Therefore, we examined the county of origin for those birds in the current dataset: 60% of birds originated from a location within the same county as the wildlife centre; 21% originated from an immediate neighbouring county; and 19% from further away. The four counties within which the wildlife centres are located range in size from 1792-5372 km^2, suggesting that they are likely to receive animals predominantly from locations within a 30 km radius. Based on these crude figures, we have made the following assumptions. For those birds which were delivered by

RSPCA personnel and which were then euthanased on receipt, we have assumed a journey time of 4h (i.e. the time from discovering the injured bird, contacting the RSPCA, waiting for someone to collect the bird and then it being delivered to the wildlife centre). Given that individuals delivered by RSPCA personnel but which died in transit would implicitly not have survived the journey, these were assumed to have survived for 2h. In contrast, birds delivered by a member of the public are likely to have had a shorter journey; they did not have to wait for someone from the RSPCA to collect the bird. We have therefore assumed that these individuals would have had journey times of 2h if they were euthanased at receipt, and 1h if they died whilst being transported.

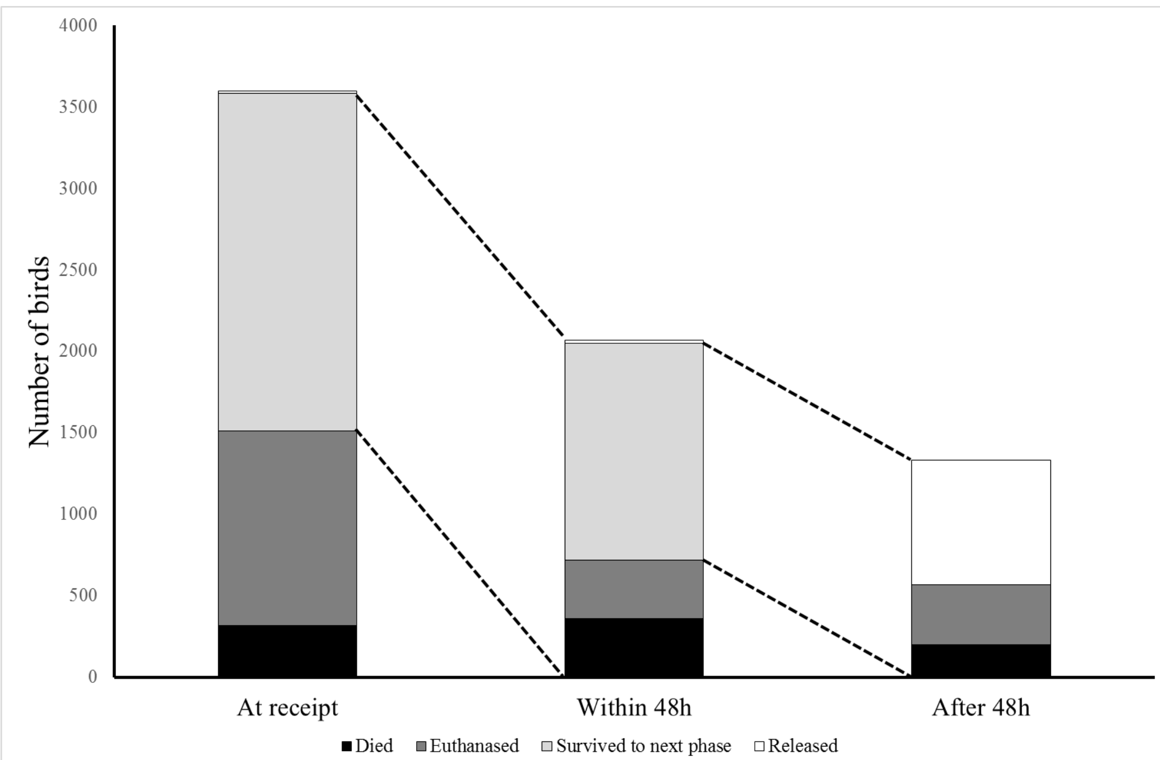
These transport times were then added to the estimated amount of time each bird spent in care if it was admitted (birds dead or euthanased at receipt had 0h in care). Individuals that were recorded as having been euthanased on day *n* after being admitted were assumed to have survived for 24*n* hours plus their journey time; this would be consistent with birds having been checked by hospital staff at the start of each day. Birds that were recorded as having died on day *n* were assumed to have died after 24*n* – 12 hours, plus their journey time. The average number of days individuals suffered was estimated for all birds and for those birds admitted following triage.

Results

Overall, 3597 individuals from 64 species were received by the four centres during 2005-2009 following an attack by a cat (Appendix 1). The most commonly received species were blackbird (24.9% of cases), wood pigeon (20.7%) and collared dove (10.4%). Red-listed species (n = 13) accounted for 16.7% (n = 602) of cases (Appendix 1), but these were dominated by the house sparrow (n = 318), starling (n = 159) and song thrush (*Turdus philomelos*: n = 99).

Collectively, 42.1% of birds were dead or euthanased at the point of receipt, and a further 20.0% and 15.7% perished within 48h and >48h of being admitted respectively (Figure 2). Overall, 0.4% were released on receipt, 0.5% within 48h of admission and 21.3% >48h after admission. These figures equate to an overall survival rate to release of 22.2% and a post-admittance survival rate (i.e. after having been triaged) of 37.9%.

Figure 2. The number of birds which died, were euthanased, survived to the next phase or were released following an attack by a cat in the three time periods of the rehabilitation process: at receipt at an RSPCA centre; within 48h of being admitted; and more than 48h after being admitted. Dashed lines indicate the relationship between the numbers of birds surviving from one time period to the next.



Factors affecting survival to release of cat-attacked birds

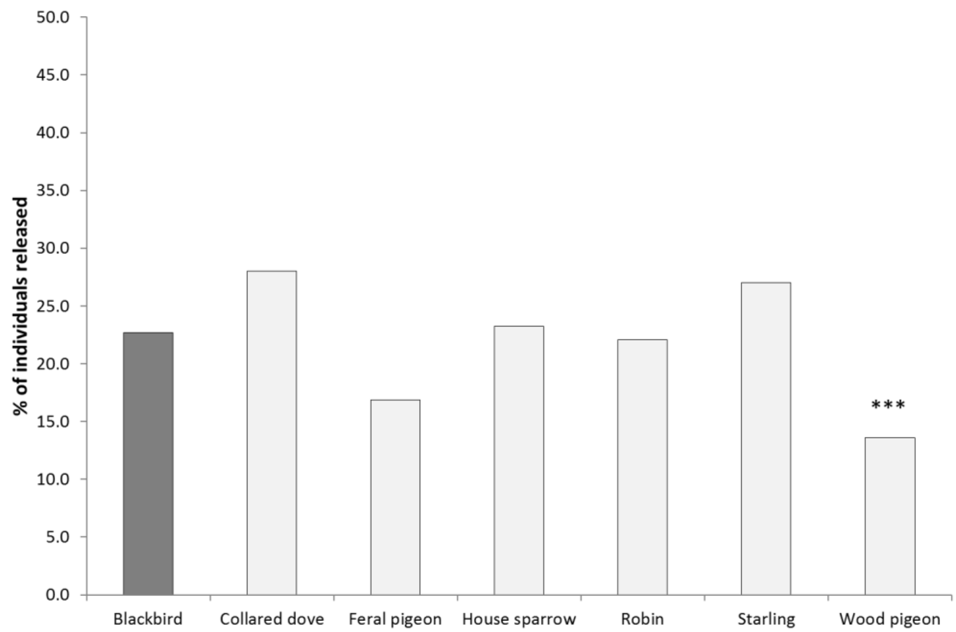
Considering the total number of individuals received at the four centres for the subset of seven species for which there were adequate sample sizes, the likelihood of surviving to release after being attacked by a cat was significantly affected by species, age, who had collected the bird and delivered it to the centre (FINDER) and the centre to which it had been delivered but not chronological year (Table 1). Release rates were significantly lower for wood pigeons (Figure 3a), adults (Figure 3b) and for birds admitted by the public (Figure 3c). In addition, one of the wildlife centres had a significantly lower release rate relative to the other three (Figure 3d).

Table 1. Summary of binary logistic regression model examining factors affecting the survival versus mortality for a subset of seven species received (i.e. before triage) by RSPCA wildlife centres from 2005-2009 inclusive (N=2709 cases); this includes animals which died in transit to the centre, which were euthanased or released at receipt, and which were admitted for care. Analysis is confined to those species for which there were ≥20 cases in both adult and juvenile age classes. Reference levels are indicated in parentheses. Model parameters are: specificity 64%; sensitivity 54%; overall classification 62%; Hosmer-Lemeshow χ^2_8 = 12.989, P = 0.112; Cox-Snell R^2 = 0.046; Nagelkerke R^2 = 0.071; cut-off threshold = 0.24

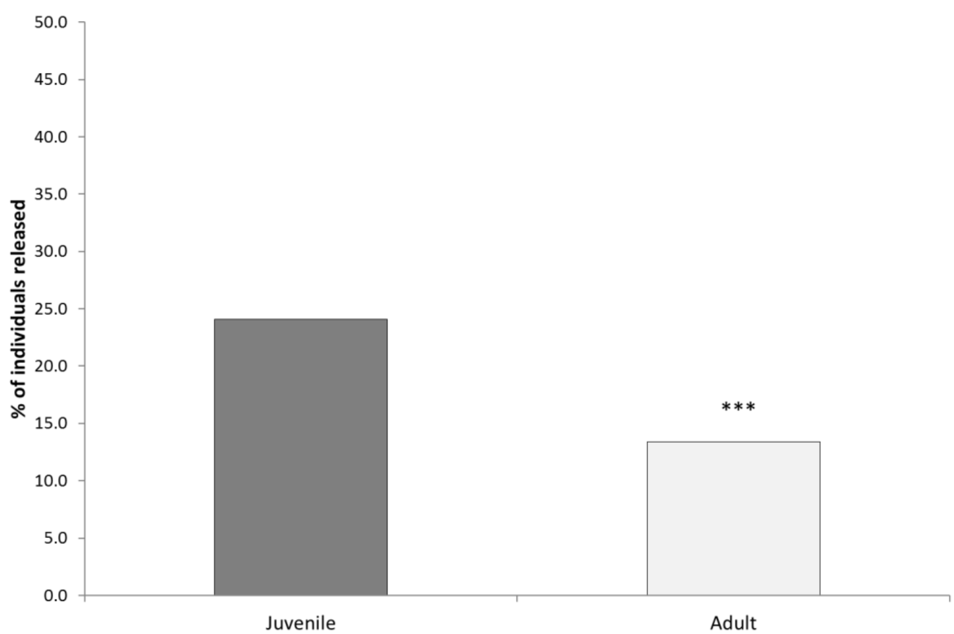
	B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I.for EXP(B)**	
							Lower	**Upper**
SPECIES(Blackbird)			41.026	6	<0.001			
Collared dove	0.251	0.145	3.016	1	0.082	1.286	0.968	1.707
Feral pigeon	-0.418	0.313	1.782	1	0.182	0.659	0.357	1.216
House sparrow	0.019	0.157	0.014	1	0.905	1.019	0.749	1.387
Robin	-0.074	0.219	0.113	1	0.737	0.929	0.605	1.426
Starling	0.188	0.199	0.889	1	0.346	1.207	0.817	1.783
Wood pigeon	-0.674	0.139	23.569	1	<0.001	0.509	0.388	0.669
AGE(Juvenile)			31.212	1	<0.001			
Adult	-0.682	0.122	31.212	1	<0.001	0.506	0.398	0.642
CENTRE(East Winch)			16.263	3	0.001			
Mallydams Wood	-0.020	0.200	0.010	1	0.919	0.980	0.662	1.451
Stapely Grange	0.084	0.135	0.383	1	0.536	1.087	0.834	1.417
West Hatch	-0.508	0.181	7.933	1	0.005	0.601	0.422	0.857
FINDER(Public)			33.581	1	<0.001			
Non-public	0.596	0.103	33.581	1	<0.001	1.815	1.484	2.221
Constant	-1.224	0.143	73.002	1	<0.001	0.294		

Figure 3. Proportion of birds released in relation to (a) species, (b) age, (c) the type of person taking the bird to the RSPCA centre and (d) the centre to which the bird was taken following an attack by a domestic cat. Data are presented for a subset of seven species. Figures include all birds received by RSPCA wildlife centres from 2005-2009 inclusive (N=2709 cases); this includes animals which died in transit to the centre, which were euthanased or released at receipt, and which were admitted for care. Reference levels are indicated by shaded columns. Asterisks denote significant differences relative to the reference level: * = P<0.05; ** = P<0.01; *** = P<0.001

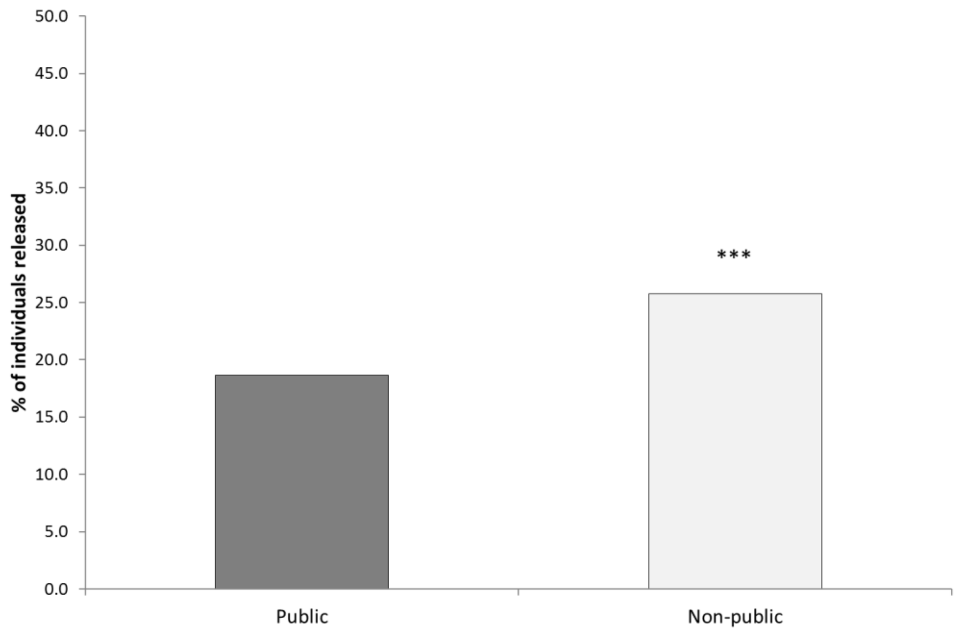
(a) Species



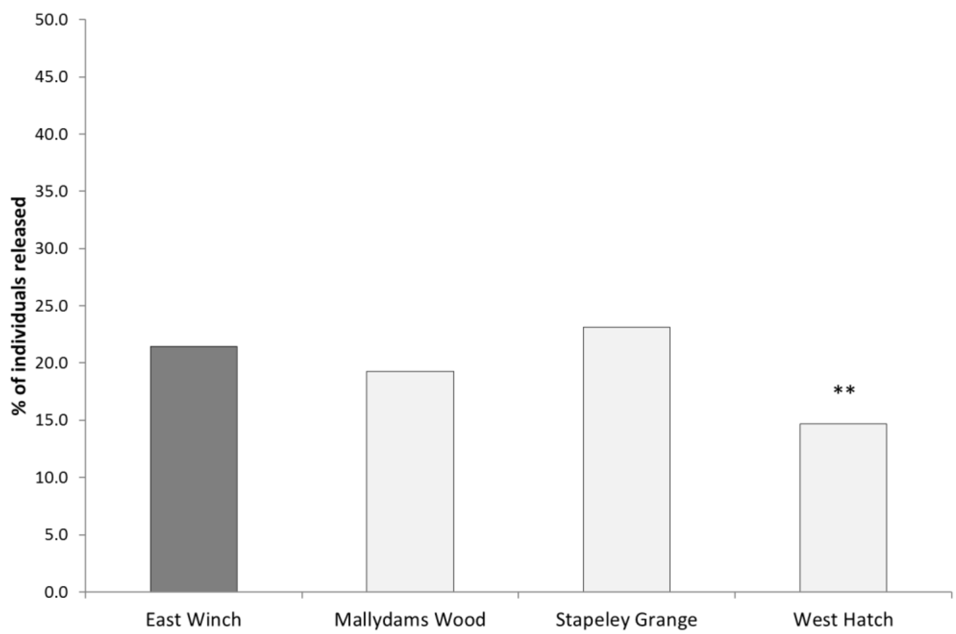
(b) Age



(c) Finder



(d) Centre



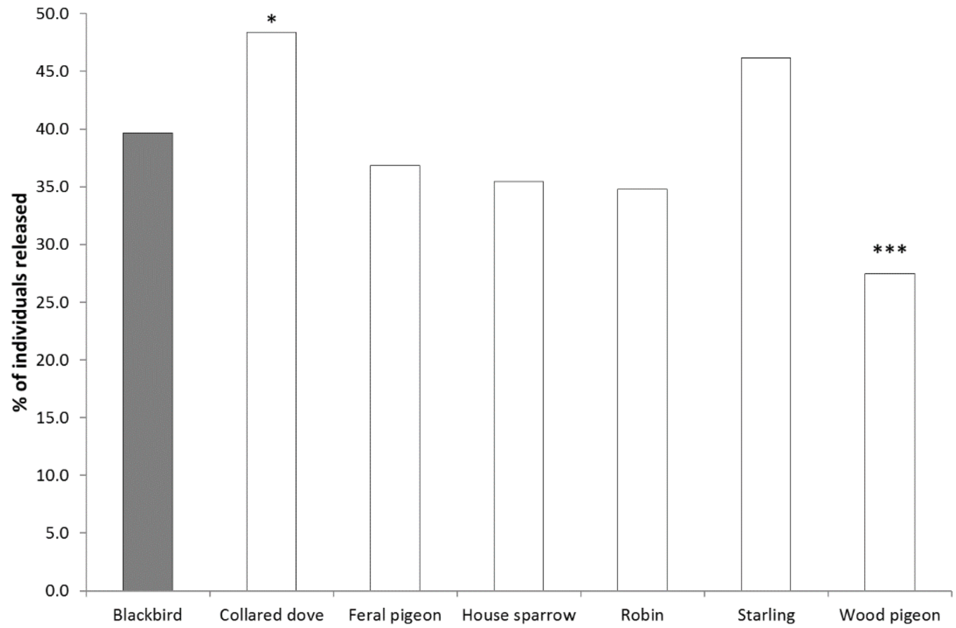
A similar pattern was also evident considering only those birds admitted for treatment (Table 2). Release rates were significantly lower for woodpigeons but higher for collared doves (Figure 4a), lower for adults (Figure 4b) and lower for birds admitted by the public (Figure 4c). Neither YEAR nor CENTRE significantly affected patterns of release for birds once they had been admitted into care.

Table 2 Summary of binary logistic regression model examining factors affecting the survival versus mortality for a subset of seven species following admittance (i.e. after triage) to RSPCA wildlife centres from 2005-2009 inclusive (N=1511). Analysis is confined to those species for which there were ≥20 cases in both adult and juvenile age classes. Reference levels are indicated in parentheses. Model parameters are: specificity 55%; sensitivity 60%; overall classification 57%; Hosmer-Lemeshow χ^2_8 = 13.985, P = 0.082; Cox-Snell R^2 = 0.033; Nagelkerke R^2 = 0.046; cut-off threshold = 0.38

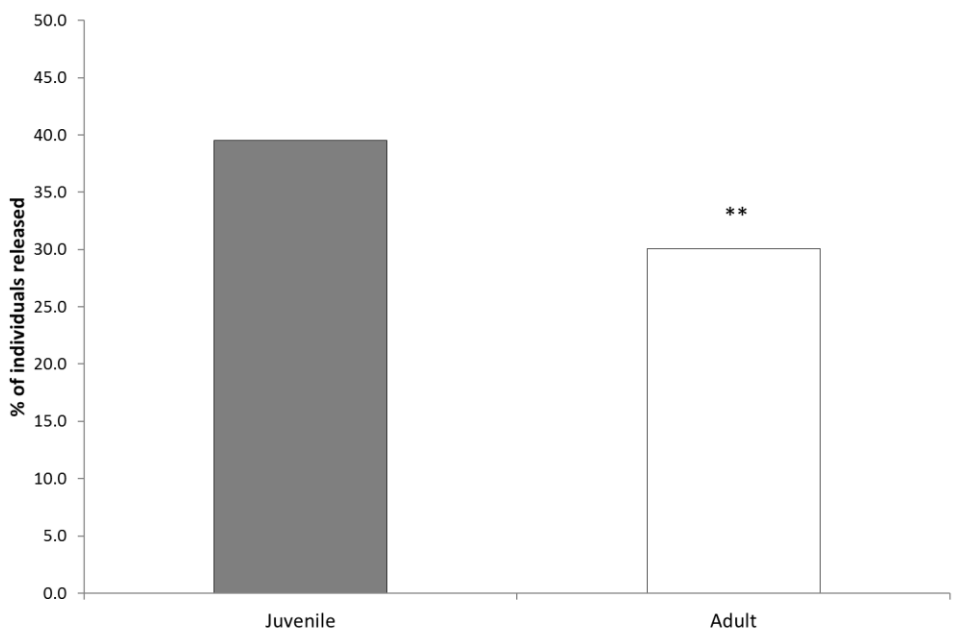
	B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I.for EXP(B)**	
							Lower	**Upper**
SPECIES(Blackbird)			32.925	6	<0.001			
Collared dove	0.358	0.167	4.574	1	0.032	1.430	1.030	1.986
Feral pigeon	-0.190	0.356	0.285	1	0.593	0.827	0.411	1.662
House sparrow	-0.171	0.173	0.976	1	0.323	0.843	0.600	1.184
Robin	-0.202	0.238	0.719	1	0.397	0.817	0.512	1.303
Starling	0.272	0.230	1.396	1	0.237	1.313	0.836	2.062
Wood pigeon	-0.600	0.154	15.070	1	<0.001	0.549	0.406	0.743
AGE(Juvenile)			8.826	1	0.003			
Adult	-0.410	0.138	8.826	1	0.003	0.664	0.507	0.870
FINDER(Public)			10.649	1	0.001			
Non-public	0.381	0.117	10.649	1	0.001	1.464	1.164	1.841
Constant	-0.462	0.099	21.858	1	<0.001	0.630		

Figure 4. Proportion of birds released in relation to (a) species, (b) age and (c) person taking the bird to the centre for a subset of seven species admitted to RSPCA wildlife centres from 2005-2009 inclusive (N=1511 cases) following an attack by a domestic cat. Reference levels are indicated by shaded columns. Asterisks denote significant differences relative to the reference level: * = P<0.05; ** = P<0.01; *** = P<0.001

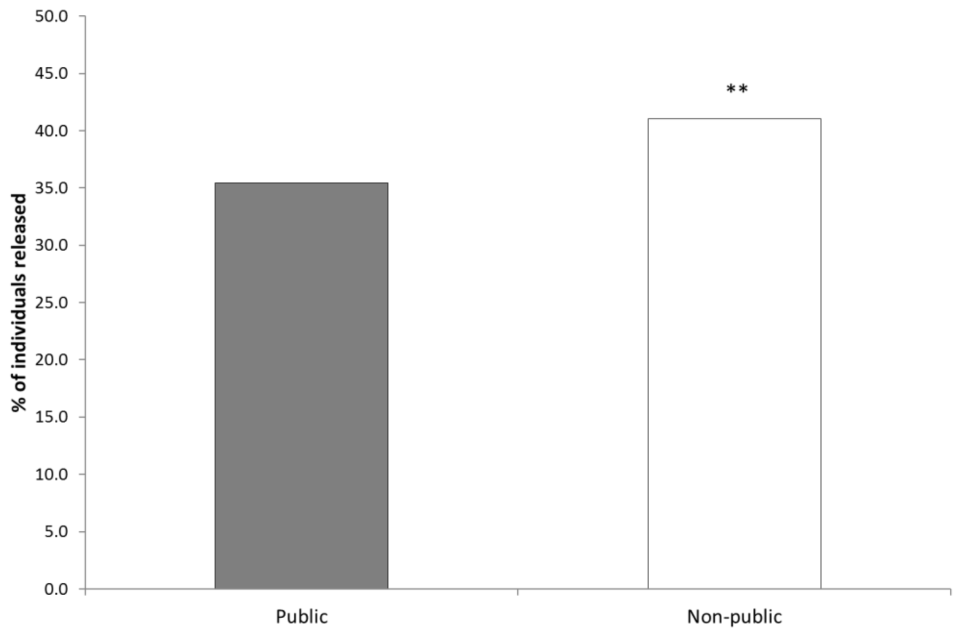
(a) Species



(b) Age



(c) Finder



Animal welfare implications

Mean survival time for all individuals that perished (i.e. died or were euthanased; N=2799) was 3.0 days (Appendix 1); for those individuals that died or were euthanased after having been admitted for care (N=1285), the mean survival time was 6.2 days. For the subset of seven species outlined in Tables 1 and 2, the equivalent figures were 3.2 and 6.9 days, respectively. These figures would over-represent suffering times if care acted to increase survival time, but under-estimate suffering times where animals were euthanased and / or if being handled caused the bird to die more quickly.

Discussion

In this study, 78% of 3597 birds presented to four wildlife centres run by the RSPCA following an attack by a cat (and 62% of 2070 birds admitted after triage) did not survive to be released. Although these figures are markedly lower than the 100% mortality rate reported by Smit *et al*

(1980) for birds admitted to Dutch wildlife hospitals, they are markedly similar to the 71% case fatality rate reported by Schenk & Souza (2014) for 809 birds submitted to the University of Tennessee Veterinary Teaching Hospital, and the 78% adult and 60% juvenile mortality rates recorded for 8,060 birds submitted to 82 wildlife rehabilitation centres throughout North America (Loyd *et al* 2017).

Although a broad range of species were attacked by cats, indicating that many species in the UK are vulnerable to pet cats, the majority of cases (77%) involved just seven species: blackbird, collared dove, feral pigeon, house sparrow, robin, starling and wood pigeon. All of these are ground-foraging species commonly found within urban and suburban areas (Tratalos *et al* 2007; Newson *et al* 2008), indicating that the species submitted for treatment tend to reflect both the higher number of cats within urban areas in the UK (Murray *et al* 2010) and the distribution of prey species (see also Loyd *et al* 2017). The potential impact of cat predation on these species at a population level is equivocal (Baker *et al* 2005, 2008; Sims *et al* 2008; Thomas *et al* 2012) but it is worth noting that both house sparrows and starlings are listed as being of conservation concern (Eaton *et al* 2009) following substantive declines in recent decades (e.g. Shaw *et al* 2008). Given that the density of pet cats is not related directly to prey availability, but is instead driven by human distribution and density (Sims *et al* 2008; Thomas *et al* 2012; Aegerter *et al* 2017), predation may become proportionately more important as species decline.

Several factors significantly affected the likelihood of individuals surviving to release, most notably species, age and the category of person who transported the bird to the centre. Birds submitted by the non-public (e.g. RSPCA collection officers) were 1.82 (based on individuals received) to 1.46 (based on individuals admitted) times as likely to survive to release as those submitted by members of the public. This result may be the consequence of some degree of selective filtering. For example, a small number of birds in the non-public category originated from veterinary surgeons (3%), who might reasonably be expected to transfer only those individuals likely to survive after they had made an initial examination, but RSPCA personnel may also, at the point of first contact, euthanase individuals they do not think would survive. This would mean individuals that were particularly badly injured would not have been delivered to the wildlife centres, potentially elevating the average survival probability for birds in the "non-public" category; that being said, it is still evident that only 26% of birds delivered by RSPCA personnel survived to be released (Figure 3c). Allied with this, but acting in the opposite direction, could be that members of the public may be more likely to take badly injured birds to the centres themselves out of sense of urgency, thereby reducing the average survival probability in the "public" category. As such, there is a need to investigate the motivations of and constraints acting upon owners in terms of the decision to deliver an injured bird to a wildlife centre (or similar organisation) or not.

Adult birds were 0.51 (received individuals) to 0.66 (admitted individuals) times as likely to have survived to release as juveniles: the same difference in age-related survival was also reported by Loyd *et al.* (2017). One possible explanation for this is the mechanics associated with catching and transporting different sized prey. Hypotheses for why pet cats return prey home include that it is an extension of the behaviour exhibited by mothers as a mechanism to train kittens to hunt or that it is a mechanism to avoid competition where cat density is high i.e. individuals retreat to the safety of their own home where other cats cannot steal the food (Morris 1986; Turner & Meister 1988; Fitzgerald & Turner 2000; Bradshaw 2013). In either case, the cat's goal is to restrain the prey and take it home as quickly as possible. All things being equal, larger prey are likely to require a greater level of force to subdue and be harder to carry in the mouth. Both these characteristics potentially mean that adult birds would be more likely to receive e.g. crush injuries and penetrating bite injuries with the subsequent risk of bacterial infection (Abrahamian & Goldstein 2011) and would be more likely to die.

Size-dependent differences in mortality rates were also partly evident at an inter-specific level with the lowest release rate observed for wood pigeons, the largest species frequently attacked by cats. However, differences in overall mortality rates for the remaining six species considered did not reflect differences in body size. In part, this is likely to be because cats attack both adults and juveniles; given that the adult mass range of one species may overlap with the juvenile mass range of another, it would be necessary to include either a species*age interaction term or mass at admission as factors in any statistical analysis. Unfortunately, neither of these options was possible in this study because of limited sample sizes and because most individuals did not have their mass recorded on receipt.

In addition, the survival rate of cat-attacked birds was significantly lower at one of the four RSPCA centres studied, but only when considering all the birds received; these differences disappeared when only those birds admitted were analysed. This would suggest that, at a basic level, all four centres were effectively applying the same triage criteria in terms of identifying those birds that should be admitted for care. However, the fact that there were still species and age differences in survival to release for those birds that were admitted suggests that these triage criteria were not effective in identifying individuals likely to die. Given the high mortality rate of birds admitted to these centres (62%), there is a significant need to develop more effective triage criteria (see *Implications for wildlife rehabilitators*).

Animal welfare implications

In this study, we have had to adopt a simplistic approach to considering the welfare implications of cat predation because of the limitations of those data available, confining comparisons to just the amount of time elapsed before death or euthanasia and how this could be managed to reduce the amount of time individuals suffer. This does, of course, overlook a range of other elements encapsulated in the wildlife rehabilitation process which may also influence welfare standards, such as the magnitude and duration of stress experienced by wild animals housed in captivity in close proximity to humans (Dickens & Romero 2009). At the current time, however, few studies have been conducted which focus on quantifying stress in wild animals in wildlife rehabilitation centres with a view to identifying mechanisms to alleviate or minimise these responses. Such studies are, therefore, urgently required. Yet despite this paucity of detailed data, the results of this study clearly have important welfare implications in two contexts: (i) the implementation of effective triage procedures once an animal has been received at a wildlife centre; and (ii) what is likely to happen to birds released by cat owners.

Implications for wildlife rehabilitators

The mortality rates observed in this study at various stages in the rehabilitation process indicate that changes to the triage procedures are required. For example, 42% of cat-attacked birds had died in transit to the wildlife centres or were euthanased on receipt, and 62% of birds admitted into the centres also died or were euthanased. Welfare standards could, therefore, be improved if Animal Collection Officers and wildlife centre staff were more clearly able to identify mortal injuries. To make such improvements, additional studies are needed which focus on quantifying factors that can be used to predict likely outcomes. These will require the quantification of physical injuries at initial collection / receipt of the animal at the centre and how these are related to survival to, and after, release (sensu Molony *et al* 2007; Kelly *et al* 2011). In addition, we would recommend that additional information on body mass is routinely recorded as this could be a useful triage criterion, especially if it was recorded in conjunction with e.g. wing length so that the two could be used to generate a general measure of physical condition and / or to record other indices of condition, such as subcutaneous fat reserves (Redfern & Clark 2001).

Implications for cat owners

One measure of the magnitude of suffering (*S*) associated with prey released alive by cat owners is: S = N*R*T, where *N* is the numbers of prey returned alive by cats, *R* is the proportion of those that are mortally injured but released, and *T* is the length of time individuals suffer before they die. As outlined above, those data available (Baker *et al* 2005; Thomas *et al* 2012) suggest that *N* is likely to be in the order of 7.2-21.6 million individuals annually given the number of pet cats owned in the UK (Murray *et al* 2010). This is a substantial number. For example, it is 1.8-5.3 times the number of regulated procedures (actions likely to cause pain, suffering or lasting harm) as defined by the Animals (Scientific Procedures) Act 1986 undertaken in Great Britain in 2012 (Anonymous 2013). It is also orders of magnitude greater than the numbers involved in other wildlife welfare issues debated recently in the UK e.g. the 160 red deer (*Cervus elaphus*), 1650 European hares (*Lepus europaeus*) and 25,000 red foxes (*Vulpes vulpes*) killed annually by dogs in England and Wales prior to the implementation of the Hunting Act 2004 (Burns *et al* 2000); the *c*. 80,000 foxes estimated to be wounded after being shot for sport and pest control (Fox *et al* 2003); and the 10,979 badgers (*Meles meles*) killed during the randomised badger culling trial to investigate the effectiveness of control strategies in the management of bovine tuberculosis

(Bourne *et al* 2007). Of those prey animals that are returned by pet cats, 11%-26% would be birds (Baker *et al* 2005; Thomas *et al* 2012): this would indicate that cat owners may receive a minimum of 0.8 million live birds each year.

Estimating the length of time mortally injured birds released by cat owners might be expected to survive is not straightforward, since even the act of picking up an injured bird might extend its time to death; this would be especially true for those birds which died after being submitted for care in a wildlife rehabilitation centre as they would have had access to shelter, food, water and veterinary treatment. Conversely, euthanasia would act to shorten the length of time to death. The degree to which these factors would act to cancel one another out is unclear, but the results of this study suggest that most individuals would be likely to die within 3 days if released injured by cat owners. Although this is a relatively short time-frame, it is worth considering that this would not likely be an acceptable period of suffering if applied to a captive animal undergoing a Home Office regulated (scientific) procedure in the UK.

The most problematic parameter to estimate currently is the proportion of animals that are released but likely to perish (*R*), as this will be dependent upon life-threatening injuries being present but which are not identified and / or are ignored by cat owners. One potential source of bias associated with using the data from the current study is that cat owners may preferentially submit only the most badly injured animals for care; this would over-estimate mortality rates, and is one possible explanation for the different survival to release rates observed for those birds submitted by members of the public versus non-public sources (Figure 3c).

However, our data clearly indicate that the identification of fatal injuries is problematic; 62% of those birds admitted into care subsequently died / needed to be killed after having been triaged by persons with extensive experience of dealing with wildlife casualties. As most cat owners would not have this level of expertise, it is reasonable to assume that there is a high probability they may fail to recognise such injuries. In addition, killing birds is a highly emotive issue and many cat owners would probably not be willing to do this and / or may feel that they are not able to do so humanely; furthermore, such killing would, if done inexpertly, raise further welfare concerns. Overall, these characteristics would potentially suggest that cat owners are likely to release most live prey animals they are presented with. Indeed, in the studies of Baker *et al* (2005) and Thomas *et al* (2012), all live animals received by cat owners were released (PJB unpublished data); this general pattern is further substantiated by the fact that only a minority of injured animals appear to be taken to wildlife centres or veterinary surgeons for treatment (e.g. in the current study, only ~700 birds were received each year by the major wildlife rehabilitation organisation in the UK).

Therefore, although further investigation into both the patterns of injuries experienced by animals attacked by cats and owners' actions when confronted by live prey is certainly warranted, it is probably reasonable to assume that most animals are simply released. Acknowledging these caveats, if we assume a conservative release rate by cat owners of 50% and that the 78% mortality rate observed in this study is representative of birds released after having been attacked, this would equate to the deaths of 0.3 million birds after being liberated, although the actual number may be substantially higher. In addition, this does not consider small mammals which are the major prey group returned home alive by pet cats in the UK (Baker *et al* 2005, 2008; Thomas *et al* 2012).

Therefore, substantive welfare improvements could be achieved if (i) the number of prey animals captured was reduced and (ii) if owners and wildlife rehabilitators were better able to identify those animals likely to die so that they could be killed humanely as soon as possible.

Given that cat owners will be the first people to physically handle animals injured by their pets, they are in the position to make the largest contribution to improving welfare standards. Most significantly, if owners were able to identify injuries that would ultimately be fatal, they could kill the animal almost as soon as it was injured. However, it is difficult to see how this could realistically be achieved. In addition to the problems associated with identifying fatal injuries, it could also lead to further welfare and ethical problems associated with the competency of householders in killing wild animals humanely and the inappropriate euthanasia of (potentially legally protected) animals if injuries were misdiagnosed.

More appropriate courses of action would be to encourage cat owners to submit more individuals to wildlife centres and veterinary surgeries for evaluation and treatment, or to adopt practices that reduce the number of birds injured per se. The former would, however, impose considerable time and financial costs if the number of casualties increased substantially, but would also generate additional costs for cat owners as well. A more cogent strategy would, therefore, be to find ways to persuade cat owners to fit anti-predation devices to their cats' collars (Ruxton *et al* 2002; Nelson *et al* 2005; Calver *et al* 2007; Gordon *et al* 2010; Hall *et al* 2015; Willson *et al* 2015) and / or impose curfews to limit the times cats are allowed out. The latter may also help to alleviate indirect negative impacts of cats, such as reduced nestling provisioning in relation to disturbance (Bonnington *et al* 2013). Given that bells can reduce predation rates by 32-53%, fitting such devices probably represents the most significant welfare benefit for wildlife as they would act to reduce the overall numbers of prey caught, not just the prey seen by the owner once they have been delivered by their pet (studies suggest that only 12-33% of prey are returned: Kays & DeWan 2004; Maclean 2007; Loyd *et al* 2013). Collaring cats is, however, associated with its own problems because of the perceived risks of injuries to the cats themselves

(Calver *et al* 2013), although this would be minimal with collars fitted with "break away" devices. In addition, cat owners do not appear to consider predation on wildlife to be a significant issue (McDonald *et al* 2015), although such arguments have generally been framed in terms of their impacts on prey populations (sensu Hall *et al* 2017) rather than emphasising any welfare benefits for wildlife.

In summary, we have estimated that a minimum of 0.8 million live birds are returned home by pet cats annually within the UK. Assuming that half of these are released by cat owners and that 78% will die from injuries received, this implies that approximately 0.3 million birds are likely to die subsequently, although the actual number may be substantially higher. However, many of the estimates made in this study are based on relatively few field data and several key assumptions. Consequently, we consider studies that help to derive better estimates of the following to be particularly important: (i) how many live prey are returned home by pet cats annually; (ii) what proportion of these prey are injured; and (iii) how do cat owners deal with live prey (e.g. what proportions are examined and released, taken to wildlife centres or simply released, etc.)?

Yet, significant improvements in the welfare of these wild animals could be achieved if cat owners were prepared to fit their cats with anti-predation devices to reduce the numbers of prey captured and if wildlife rehabilitators were able to triage animals more effectively so that they could be killed humanely as early as possible. Studies that (iv) identify the constraints or motivations of cat owners which affect e.g. their actions when confronted with live prey and attitudes towards the impacts of their pets on wildlife are therefore also warranted (e.g. McDonald *et al* 2015), as these will help in the development of strategies to alleviate these impacts. Finally, (v) diagnostic criteria need to be identified which can be used to improve the effectiveness of triage procedures.

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Appendix 1. Fate of individual birds admitted to four RSPCA wildlife centres during 2005-2009 inclusive following an attack by a domestic cat. Figures denote the number of individuals that died (D), were euthanased (E) or were released (R) at receipt at the hospital, within 48h of being admitted and more than 48h after being admitted. "Status" refers to conservation status of species as reviewed by Eaton *et al* (2009): G = green, A = amber, R = red, N = not assessed (see text for details).

Species	**Status**[1]	**At receipt**			**Within 48h**			**After 48h**			**Total**	**Suffering**
		D	**E**	**R**	**D**	**E**	**R**	**D**	**E**	**R**		
Black-headed gull *Larus ribidundus*	A	0	1	0	0	0	0	0	0	2	3	0.2
Blackbird *Turdus merula*	G	89	297	1	76	100	0	55	76	203	897	3.1
Blue tit *Parus caeruleus*	G	9	10	0	13	2	1	5	1	12	53	1.6
Bullfinch *Pyrrhula pyrrhula*	A	2	0	0	0	0	0	0	0	1	3	<0.1
Canada goose *Branta canadensis*	N	1	1	0	0	0	0	0	0	0	2	0.1
Carrion crow *Corvus corone*	G	0	7	0	2	2	0	0	6	0	17	2.4
Chaffinch *Fringilla coelebs*	G	4	6	0	7	3	1	1	0	8	30	0.9
Chiffchaff *Phylloscopus collybita*	G	1	0	0	0	0	0	0	0	0	1	0.1
Coal tit *Parus ater*	G	0	2	1	1	0	0	0	0	1	5	0.3
Collared dove *Stretopelia decaocto*	G	18	140	0	15	38	1	9	50	104	375	3.3
Dunnock *Prunella modularis*	G	12	23	2	23	12	0	11	5	45	133	2.0
Feral pigeon *Columba livia*	G	2	43	0	3	11	0	5	5	14	83	2.6
Fieldfare *Turdus pilaris*	R	0	0	0	0	1	0	0	0	0	1	1.2
Goldcrest *Regulus regulus*	G	2	1	0	2	0	0	0	0	0	5	0.3
Goldfinch *Carduelis carduelis*	G	2	5	0	12	4	0	2	4	7	36	3.2
Great crested grebe *Podiceps cristatus*	G	0	0	0	0	0	0	2	0	0	2	4.7
Great spotted woodpecker *Dendrocopos major*	G	2	1	1	3	1	1	0	0	3	12	0.6
Great tit *Parus major*	G	2	14	1	9	3	0	2	1	9	41	1.2
Green woodpecker *Picus viridis*	A	0	2	0	3	0	0	3	2	0	10	4.0
Greenfinch *Carduelis chloris*	G	17	19	1	4	2	0	7	4	16	70	2.5
Grey heron *Ardea cinerea*	G	0	0	0	0	0	0	0	0	1	1	-
Greylag goose *Anser anser*	A	0	1	0	0	0	0	0	0	0	1	0.1
Herring gull *Larus argentatus*	R	0	2	0	0	1	0	0	3	3	9	8.9

House martin *Delichon urbica*	A	1	7	0	0	4	3	0	2	6	23	3.7
House sparrow *Passer domesticus*	R	38	75	2	46	17	1	38	30	71	318	4.3
Jackdaw *Corvus monedula*	G	2	1	0	0	2	1	0	1	5	12	6.2
Jay *Garrulus glandarius*	G	1	0	0	0	0	0	0	1	0	2	12.6
Kingfisher *Alcedo atthis*	A	0	0	0	2	0	0	0	0	0	2	0.6
Lapwing *Vanellus vanellus*	R	0	0	0	0	0	0	0	1	0	1	11.2
Lesser spotted woodpecker *Dendrocopos leucotos*	R	0	0	0	1	0	0	0	0	0	1	1.6
Linnet *Carduelis cannabina*	R	0	1	0	0	0	0	0	0	1	2	0.1
Little owl *Athene noctua*	N	0	0	0	2	2	0	0	2	1	7	6.9
Long-tailed tit *Aegithalos caudatus*	G	4	0	0	1	0	0	2	0	0	7	2.3
Magpie *Pica pica*	G	2	15	0	3	9	0	0	1	11	41	1.0
Mallard *Anas platyrhynchos*	A	5	8	0	10	5	0	0	2	11	41	2.4
Meadow pipit *Anthus pratensis*	A	0	1	0	1	0	0	0	0	0	2	0.8
Mistle thrush *Turdus viscivorus*	A	3	5	0	2	1	0	0	3	6	20	3.0
Moorhen *Gallinula chloropus*	G	2	2	0	5	1	0	1	2	4	17	4.6
Mute swan *Cygnus olor*	G	0	0	0	0	0	1	0	0	0	1	-
Nightjar *Caprimulgus europaeus*	R	0	0	0	0	0	2	0	0	0	2	-
Nuthatch *Sitta europaea*	G	1	1	0	0	0	0	0	0	1	3	0.1
Pheasant *Phasianus colchicus*	N	0	3	0	5	2	0	1	0	8	19	0.9
Pied wagtail *Motacilla alba*	G	1	0	0	1	0	0	0	0	0	2	0.3
Quail *Coturnix coturnix*	A	0	2	0	0	1	0	0	1	1	5	1.6
Red-legged partridge *Alectoris rufa*	N	0	2	0	1	2	0	0	0	3	8	1.2
Redwing *Turdus iliacus*	R	1	1	0	1	0	0	0	0	0	3	0.6
Robin *Erithacus rubecula*	G	18	35	0	30	10	0	14	6	32	145	2.5
Rook *Corvus frugilegus*	G	0	1	0	0	0	0	0	1	0	2	8.6
Sedge warbler *Acrocephalus schoenobaenus*	G	0	0	0	0	1	0	0	0	0	1	1.2
Skylark *Alauda arvensis*	R	0	1	0	0	0	0	0	0	0	1	0.1
Song thrush *Turdus philomelos*	R	13	28	0	16	7	0	2	8	25	99	1.6
Sparrowhawk *Accipiter nisus*	G	1	2	0	0	0	0	4	0	1	8	2.3

Spotted flycatcher *Muscicapa striata*	R	2	1	0	0	0	0	0	2	0	5	17.7
Starling *Sturnus vulgaris*	R	14	53	1	17	12	0	5	15	42	159	2.6
Stock dove *Columba oenas*	A	1	0	0	0	0	0	0	0	1	2	<0.1
Swallow *Hirundo rustica*	A	0	2	0	2	0	0	0	2	1	7	8.9
Swift *Apus apus*	A	1	8	3	2	3	4	0	3	2	26	1.3
Tree sparrow *Passer montanus*	R	0	0	0	0	1	0	0	0	0	1	1.1
Water rail *Rallus aquaticus*	G	0	0	0	0	0	0	0	1	0	1	3.2
Whitethroat *Sylvia communis*	A	1	0	0	0	0	0	0	0	0	1	<0.1
Willow warbler *Phylloscopus trochilus*	A	0	1	0	0	0	0	0	0	0	1	0.1
Wood pigeon *Columba palumbus*	G	25	350	0	26	92	2	27	122	99	743	3.1
Woodcock *Scolopax rusticola*	A	0	0	0	1	1	1	0	0	1	4	1.4
Wren *Troglodytes troglodytes*	G	16	16	1	12	7	0	3	3	4	62	2.0
Total no. of individuals		***316***	***1197***	***14***	***360***	***360***	***19***	***199***	***366***	***766***	***3597***	**3.0**
No. of species		***36***	***44***	***10***	***36***	***33***	***12***	***21***	***32***	***38***	***64***	***61***