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Research Paper

An updated estimate of the number of birds killed by outdoor cats in Canada

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ABSTRACT. Domestic cats, *Felis catus*, can be found almost everywhere in the world and estimating their impact on wildlife, including birds, requires the most up-to-date information. There are an estimated 9.3 million pet cats in Canada, 30–60% of which are given unrestricted access to the outdoors. With the best available data in 2013, cats were estimated to kill between 105–348 million birds per year in Canada, making them the leading measurable cause of bird mortality in the country. However, a decade later, research on outdoor cats and their predation of birds has increased considerably, providing an opportunity to revisit this mortality estimate. Using recent data on predation rates and cat abundance, we estimated that cats kill between 19 and 197 million birds per year in Canada, 71% lower than the earlier estimate. This does not mean that cat populations or predation rates on birds have declined since the previous estimate. Rather, we suggest that the difference can be primarily attributed to lower outdoor cat abundance estimated from field surveys compared to previously used cat ownership surveys and media reports of shelter intake data. Although the estimated number of birds killed annually by cats is considerably lower than the previous estimate, outdoor cats remain a serious concern for native bird populations.

Une estimation actualisée du nombre d'oiseaux tués par les chats d'extérieur au Canada

RÉSUMÉ. Les chats domestiques, *Felis catus*, sont présents presque partout dans le monde et l'estimation de leur impact sur la faune sauvage, y compris les oiseaux, nécessite des informations actualisées. On estime à 9,3 millions le nombre de chats domestiques au Canada, dont 30 à 60 % disposent d'un accès illimité à l'extérieur. Selon les meilleures données disponibles en 2013, on estime que les chats tuent entre 105 et 348 millions d'oiseaux par an au Canada, ce qui en fait la première cause mesurable de mortalité des oiseaux dans le pays. Cependant, dix ans plus tard, les recherches sur les chats d'extérieur et leur prédation sur les oiseaux sont considérablement plus nombreuses, ce qui nous donne l'opportunité de réexaminer cette estimation de la mortalité. En utilisant des données récentes sur les taux de prédation et l'abondance des chats, nous avons estimé que ces derniers tuent entre 19 et 197 millions d'oiseaux par an au Canada, soit 71 % de moins que l'estimation précédente. Cela ne signifie pas que les populations de chats ou les taux de prédation sur les oiseaux ont diminué depuis l'estimation précédente. Selon nous, cette différence est principalement attribuable à une plus faible abondance de chats d'extérieur estimée par les enquêtes sur le terrain par rapport aux enquêtes sur la propriété des chats utilisées précédemment et aux rapports des médias sur les données d'admission dans les refuges. Bien que le nombre estimé d'oiseaux tués chaque année par les chats soit considérablement inférieur à l'estimation précédente, les chats d'extérieur représentent une menace importante pour les populations d'oiseaux indigènes.

Key Words: *avian; invasive species; Felis catus; feral; predation*

INTRODUCTION

Domestic cats occur in almost every ecosystem on the planet (O' Brien and Johnson 2007) and, when let outdoors, they can exert considerable predation pressure on wildlife (Blancher 2013, Loss et al. 2013, Woinarski et al. 2017, Legge et al. 2020, Lepczyk et al. 2023). The most dramatic evidence of their impact comes from the fact that cats have directly caused 63 extinctions worldwide, including 40 bird species (Doherty et al. 2016), all on islands, where evolutionarily naïve prey live in the absence of mammalian predators (Doherty et al. 2016). Although no continental extinctions have been solely attributed to cats, the sheer number of cats in continental areas means that they have the potential to negatively influence many native bird populations (Loss and Marra 2017). Most birds face simultaneous threats, such as habitat loss, climate change, and window collisions (Calvert et al. 2013, Loss et al. 2013, Woinarski et al. 2017), which, cumulatively, have led to an estimated loss of 3 billion birds in North America since 1970 (Rosenburg et al. 2019).

In Canada, the estimated number of owned (i.e., pet) cats is as high as 9.5 million (Canadian Federation of Humane Societies 2017), 30–60% of which are let outdoors (Stewardship Centre for British Columbia 2017, Tan et al. 2021), with another 1.5–4.1 million unowned cats in Canada (Blancher 2013). Accurate and up-to-date estimates of cat-induced mortality on wildlife are needed to assess the magnitude of the impacts of cats on birds in

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Canada. Over 10 years ago, Blancher (2013) estimated that cats in Canada killed between 105 and 348 million birds per year, which made them the leading measurable anthropogenic cause of bird mortality in the country (Calvert et al. 2013). However, since 2013, research on domestic cats has increased considerably, partly as a response to high wildlife predation estimates, first reported in the United States (Loss et al. 2013) and then elsewhere (Blancher 2013, Woinarski et al. 2017). This has resulted in growing media attention on outdoor domestic cats (Gow et al. 2022) and an increased desire of many parties to better understand the degree to which cats impact wildlife.

We used recent peer-reviewed studies to update the estimate of the number of birds killed by outdoor cats in Canada. Because no population surveys were conducted for cats in Canada at the time of Blancher's (2013) study, the total population of cats was estimated using surveys from grey literature of pet ownership rates and media reports of shelter intake data. Field surveys using walking transects (Flockhart et al. 2016, Hand 2019) or trail cameras (Gow et al. 2024) that have been conducted after the publication of Blancher's (2013) mortality estimate should provide a more accurate estimate of how many cats are outdoors. Furthermore, since Blancher (2013), the number of studies that have estimated cat predation rates (e.g., Loyd et al. 2013a, Dickman and Newsome 2015, Kitts-Morgan et al. 2015, McGregor et al. 2015, Hernandez et al. 2018, Pemberton and Ruxton 2019) has almost doubled from 28 to 53. A portion of these newer studies have also used animal-borne cameras, which provide more accurate predation rate estimates compared to traditionally used owner surveys (Loyd et al. 2013a, Morling 2014, McGregor et al. 2015, Hernandez et al. 2018, Bruce et al. 2019, Seymour et al. 2020). Animal-borne cameras can also generate predation rate estimates of unowned cats (McGregor et al. 2015, Hernandez et al. 2018, Huck and Watson 2019), something that was originally only possible using scat or stomach-content analysis, both of which may be biased because cats do not eat all the prey they capture (Loyd et al. 2013a, McGregor et al. 2015, Seymour et al. 2020). In addition, recent studies that have used the more popular method of surveying cat owners on the number of prey brought home have larger sample sizes and have been conducted over multiple sampling seasons, providing more robust data (Dickman and Newsome 2015, Willson et al. 2015, Pemberton and Ruxton 2019, Pirie et al. 2022, Lockwood et al. 2025).

METHODS

Blancher (2013) estimated the total number of birds killed by cats per year in Canada, K, using the following formula:

$$K = K_u + K_r + K_f \quad (1)$$

Where, K_u is the number of birds killed annually by urban owned cats, K_r is the number of birds killed annually by rural owned cats, and K_f is the number of birds killed annually by unowned cats. K_u was estimated as:

$$K_u = n_{owned} \times (1 - p_r) \times p_{out} \times B_u \times C \quad (2)$$

where, n_{owned} is the number of owned cats in Canada, p_r is the proportion of cats that live in rural areas, p_{out} is the proportion of cats that are let outdoors, B_u is the number of birds returned to owners annually per urban owned cat, and C is a correction factor to account for the ratio of prey returned to owners to actual number of kills. K_r was estimated as:

$$K_r = n_{owned} \times p_r \times p_{out} \times B_r \times C \quad (3)$$

where B_r is the number birds returned to owners annually per rural owned cat and all other parameters are the same in Equation 2. Finally, K_f was estimated as:

$$K_f = n_{unowned} \times B_f \quad (4)$$

where $n_{unowned}$ is the number of unowned outdoor cats in Canada and B_f is the annual bird predation rate of an unowned outdoor cat.

To carry forward uncertainty in these estimates, Blancher (2013) used a Monte Carlo approach, iterating each formula 10,000 times using a fitted distribution for each parameter: n_{owned} was assumed to be a normal distribution, B_u was assumed to be as an uniform distribution centered around the median instead of the mean, and all other parameters were assumed to be a uniform distribution centered around the mean. The definitions and range of values used by Blancher (2013) are summarized in Table 1. We briefly detail Blancher's (2013) justifications for each parameter in Appendix 1.

Modifying Blancher's (2013) formulas

Because there were no field based estimates of cat abundance from any Canadian locality, to estimate owned outdoor cats, Blancher (2013) used cat owner surveys to estimate the number of owned cats in Canada, and then multiplied this number by the percentage of cats estimated to be let outside. He then used media reports of shelter intake data to estimate the number of unowned outdoor cats. However, since 2013, there have been five studies that have estimated cat abundance using field surveys (Table 2). Thus, we modified the terms in Blancher's (2013) total mortality formulas such that the number of birds killed annually by urban owned cats, K_u, was calculated as:

$$K_u = P_u \times B_u \times C \quad (5)$$

where P_u is the total population of urban owned cats in Canada and B_u and C are the same as Equation 2. K_r is now estimated by:

$$K_r = P_r \times B_r \times R \times C \quad (6)$$

where P_r is the total population of rural owned cats in Canada, R is an adjustment to account for the higher ratio of cats in rural homes compared to urban homes, and B_r and C are the same as Equation 3. Finally, the number of birds killed annually by unowned cats, K_f, can be estimated by:

$$K_f = P_f \times B_f \quad (7)$$

Table 1. Parameters and range of values used in annual bird mortality formulas (both Blancher method and field survey method). Blancher's (2013) range of values are provided for comparison. The distribution of each parameter, whether it was normally distributed, uniformly distributed, or uniformly distributed but median-centered is indicated. If the parameter was included in both the present study and Blancher (2013) the distribution used in both analyses is indicated. For parameters treated as uniform median-centered distributions, the median is indicated in parentheses.

Parameter	Acronym	Range of values, this study	Range of values, Blancher (2013)	Distribution
Parameters related to the number of cats in Canada				
Number of owned cats in Canada	n_{owned}	Not used	8,500,000 +/- 0.25M	Normal
Percent of rural owned cats	p_r	Not used	0.27 - 0.33	Uniform
Percent of cats with access to outdoors	p_{out}	Not used	0.40–0.70	Uniform
Number of unowned cats in Canada	$n_{unowned}$	Not used	1.4–4.2 million	Uniform
Population of outdoor urban cats in Canada	P_u	0.76–4.1 million	Not used	Uniform
Population of outdoor rural cats in Canada	P_r	0.065 - 0.35 million	Not used	Uniform
Population of unowned cats in Canada	P_f	0.26–1.03 million	Not used	Uniform
Adjustment for rural cat ownership rates	R	1.5–2.0	Not used	Uniform
Parameters related to the bird predation rates by cats in Canada				
Birds returned/urban outdoor owned cat/year	B_u	0 - 10.2 (2.1 median)	0.6 - 6.7 (2.8 median)	Median-centered
Birds returned/rural outdoor owned cat/year	B_r	2.6–8 (4.5 median)	2.8–14.0	Median-centered / Uniform
Adjustment for undetected prey	C	4.3–5.6	2–5.8	Uniform
Birds killed/unowned cat/year	B_f	8.7–64 (28.5 median)	24–64	Median-centered / Uniform

Table 2. Low and high estimates of the number of cats (*Felis catus*) in five Canadian localities. The population estimates were multiplied by the human population in the city to give low and high estimates of cats per person. Cats per person estimates were then multiplied with total urban and rural human population to get parameter estimates for cat populations in Canada.

City[1]	Number of cats	Human population[2]	Cats/person
Owned and unowned cats			
Gatineau, PQ	8905–48,419	291,041	0.031–0.166
Guelph, ON	6145–9966	155,578	0.040–0.064
Vancouver, BC	22,763–124,484	678,984	0.034–0.183
South Okanagan, BC	2858–16,310	12,769	0.224–1.277
Unowned cats			
Windsor, ON	1361–2537	229,660	0.006–0.010

[1] Sources: Guelph: Flockhart et al. 2016, Windsor: Hand 2019, Gatineau: Gow et al. 2024, Vancouver: E. A. G., *unpublished data*.
[2] Statistics Canada 2023.

where P_f is the total population of unowned cats in Canada and B_f is the same as Equation 4. In these modified formulas, the abundance of cats, P_u, P_r, P_f are derived from field surveys of local areas and extrapolated to the national level.

Updating annual mortality parameters

We reviewed recent literature to update the parameter values for annual mortality equations (methodological details of the literature reviews are outlined in Appendix 1). Parameter ranges are summarized in Table 1 and provide a comparison with Blancher (2013)'s ranges. We outline our rationale for parameter values below.

B_u: Number of birds brought home to owners by urban owned cats

Along with the 9 studies originally considered by Blancher (2013), we used an additional 12 owner self-report studies and four camera studies (Table 3). Despite the advent of animal-borne cameras, documenting prey brought home to owners is still by far the most widely used method to estimate predation rates. Although there are still no predation rate studies that have been published on cats in Canada, we extracted information from cat predation studies conducted in other temperate regions. From each of these studies, we calculated the number of birds brought home per cat per year (Table 3). As done in Blancher (2013), studies that were not conducted for an entire year were extrapolated to a full year based on the average proportion of birds returned per month. Because cats do not return every bird that they kill (Loyd et al. 2013a, Bruce et al. 2019, Seymour et al. 2020), prey returns were corrected using an adjustment parameter, C. For the four animal-borne camera studies (Morling 2014, Bruce et al. 2019, Loyd et al. 2013a, Seymour et al. 2020) that directly recorded predation, we calculated the number of birds brought home using only the instances of footage, indicated by the study, where the cat was observed to bring a bird home. This excluded birds that were eaten at time of capture and birds abandoned after capture. Among the studies considered by Blancher (2013), as well as the more recent ones, the lowest reported number of birds brought to owners annually was 0 (Morling 2014, Bruce et al. 2019) and the highest was 10.2 (Ruxton et al. 2002). Therefore, the range of values were estimated as 0–10.2 with the median at 2.1 (Table 1). As done in Blancher (2013), to not bias predation rates to uncommon high values, we assumed the distribution of this parameter to be uniform but centered by the median. In other words, 50% of values were uniformly distributed on either side of the median. We chose a uniform distribution over other median-centered distributions (pseudo-normal etc.) because other distributions would require additional parameters that would be difficult to parameterize due to the lack information on cat predation rates in Canada."

B_r: Number of birds brought home to owners by rural cats

Since Blancher (2013), there have been two published papers that have estimated predation rates of birds by rural cats. One paper reported data from two separate studies (McDonald et al. 2015), generating a total of three predation rate estimates (Table 3). The

Table 3. Rates of birds returned or killed by cats (*Felis catus*), calculated from data provided in listed studies, adjusted to a year-round rate where data were seasonal. Birds returned by owned cats from camera data refer to instances in footage where cats were seen bringing birds home. Bolded predation rates are the medians. Whether the study was newly added to this analysis or considered both now and in 2013 is indicated under the Study Inclusion column.

Birds/ cat/year	Method[†]	Study	Location	Study inclusion[‡]
Urban owned cats				
0	cam	Morling 2014	Western Cape, SA	This study
0	cam	Bruce et al. 2019	Aukland Region, Aukland, NZ	This study
0.5	pr	Lockwood et al. 2025	UK	This study
0.6	pr	Baker et al. 2008	Bristol, UK	Both
0.9	pr	Thomas et al. 2012	Berkshire, UK	This study
0.9	cam	Seymour et al. 2020	Western Cape, SA	This study
1.0	cam	Loyd et al. 2013a	Georgia, USA	This study
1.3	pr	Morling 2014	Western Cape, SA	This study
1.4	pr	Pirie et al. 2022	Berkshire, UK	This study
1.6	pr	Kays and DeWan 2004	New York, USA	Both
1.6	pr	Willson et al. 2015	New York, USA	This study
1.8	pr	Tschanz et al. 2011	Menzingen, SWI	Both
2.1	pr	George 2010	Western Cape, SA	This study
2.8	pr	Barratt 1998	New South Wales AUS	Both
2.8	pr	Gillies and Clout 2003	Aukland Region, NZ	Both
3	pr	Krauze-Gryz et al. 2019	Poland	This study
3.3	pr	Dickman and Newsome 2015	New South Wales, AUS	This study
3.4	pr	Fiore et al. *unpublished manuscript*	Kansas, USA	Both
5.1	pr	Hansen 2010	Banks Peninsula, NZ	This study
5.6	pr	Churcher and Lawton 1987	Bedfordshire, UK	Both
6.3	pr	van Heezik et al. 2010	Otago, NZ	Both
6.6	pr	Hall et al. 2015	South West Land Division, AUS	This study
6.7	pr	Woods et al. 2003	UK	Both
6.7	pr	Nelson et al. 2005	UK	This study
10.2	pr	Ruxton et al. 2002	northwest England, UK	This study
Rural owned cats				
2.6	pr	McDonald et al. 2015	Dumfries and Galloway, UK	This study
4.5	pr	McDonald et al. 2015	Cornwall, UK	This study
8	pr	Kauhala et al. 2015	southwest Finland, FN	This study
Unowned cats				
8.7	sc	Kitts-Morgan et al. 2015	Georgia, USA	This study
15	cam	McGregor et al. 2015	Kimberley, AUS	This study
24	st	Parmalee 1953	Texas, USA	Both
26.3	obs	Dickman and Newsome 2015	Multiple	This study
27	st	Coman and Brunner 1972	Victoria, AUS	Both
30	st	Hutchings 2003	Victoria, AUS	Both
44	st	Errington 1936	Wisconsin, USA	Both
48	st	McMurray and Sperry 1941	Oklahoma, USA	Both
51	st	Eberhard 1954	Pennsylvania, USA	Both
64	st	Llewellyn and Uhler 1952	Maryland, USA	Both

[†] Methods are as follows, pr: prey return, cam: animal-borne camera, st: stomach-content analysis, sc: scat analysis, obs: direct observations, and est: nation-wide estimate.
[‡] Study inclusion is as follows: "This study" indicates the predation rate estimate has been added to the present study and was not in Blancher (2013), and "Both" indicates the predation rate was included in both the present study and Blancher (2013).

lowest number of birds returned by rural cats per year was estimated to be 2.6 (McDonald et al. 2015) and the highest was 8 (Kauhala et al. 2015). Thus, we set the parameter range to be 2.6–8 and assumed the distribution to be uniform but median-centered, with 50% of values uniformly distributed on either side of the median (4.5), as described previously.

C: Correction for birds killed undetected by prey returns

Using animal-borne cameras on cats, Loyd et al. (2013a) found that 4.3 times more birds were killed than brought home by their study cats in Georgia, USA. In South Africa, Seymour et al. (2020) reported that cats killed 5.6 times more birds than they brought home. We used the lowest estimated adjustment value (4.3) as the minimum value and used the highest (5.6) as the maximum value. This parameter range was treated as a uniform continuous distribution.

B_f: Number of birds killed by unowned cats

Since 2013, five studies have been conducted to estimate the number of birds killed by unowned cats (Table 1). These five studies generally report lower predation rates than the ones used by Blancher (2013). Among previously reported studies by Blancher (2013) and the new studies outlined here, the lowest predation rate, 0.9 birds killed per cat per year, was estimated using animal-borne cameras (Hernandez et al. 2018). Two birds were killed across 681 hours of recorded footage from 29 cats. This low bird predation rate could reflect prey availability at the study site, which was located on barrier islands off the coast of Georgia, USA (Hernandez et al. 2018). An earlier study of unowned cat scats from mainland Georgia estimated annual bird predation rates to be 8.7 (Kitts-Morgan et al. 2015). Among all considered studies, the highest predation rate was from an Australian-wide analysis of scat and stomach studies that estimated 129 birds were killed annually per cat (Woinarski et al. 2017). To update the parameter range, we first removed the lowest and highest estimate (0.9 and 129) because they appeared to be outliers and then set the minimum and maximum to be 8.7 and 64. We assumed the distribution to be uniform but median-centered, with 50% of values distributed uniformly on either side of the median (28.5).

P_u, P_r, and P_f

Since Blancher (2013), cat populations have been estimated for five Canadian localities (Table 2): Gatineau, QC (Gow et al. 2024), Guelph, ON (Flockhart et al. 2016), Windsor, ON (Hand 2019), Vancouver, BC (E. A. G. *unpublished data*), and the south Okanagan region, BC (between Okanagan Falls in the north to Osoyoos in the south; Wilson 2025). The studies used either walking surveys or trail cameras to estimate cat abundance. We divided low and high estimates of cat abundances by the city's human population to get low and high estimates of the number of cats per person (Table 2). Three studies (Flockhart et al. 2016, Gow et al. 2024; E. A. G. *unpublished data*) did not distinguish between owned or unowned cats in their abundance estimates. Thus, we estimated the proportion of unowned cats to all cats for both urban and rural areas. In Gatineau, unowned cats accounted from anywhere between 18 and 73% of the total number of outdoor cats (Gow et al. 2024), whereas, in the more rural south Okanagan, unowned outdoor cats were estimated to be between 68 and 82% of the outdoor cat population (Wilson 2025). We assumed unowned cat populations were on the low end of the population estimates (18% for urban areas, 68% for rural areas). We calculated the mean of the minimum estimated cats per person from the five studies (Table 2) and did the same for high estimates of the number of cats per person (Table 2). We then extrapolated the means to the entire Canadian urban, rural, and total human population (respectively, 30,389,999; 6,601,982; and 36,991,981

persons; Statistics Canada 2023) to give an urban cat population parameter range (P_u), a rural cat population parameter range (P_r), and an unowned cat population parameter range (P_f; Table 1). We assumed a uniform continuous distribution for the three population parameter ranges.

R - Adjustment for rural cat populations

To adjust for the observation that people living in rural areas keep more cats per household than people in urban areas, we set an adjustment parameter to be between 1.5 to 2.0 and treated it as uniform continuous distribution, based on Lepczyk et al. (2004).

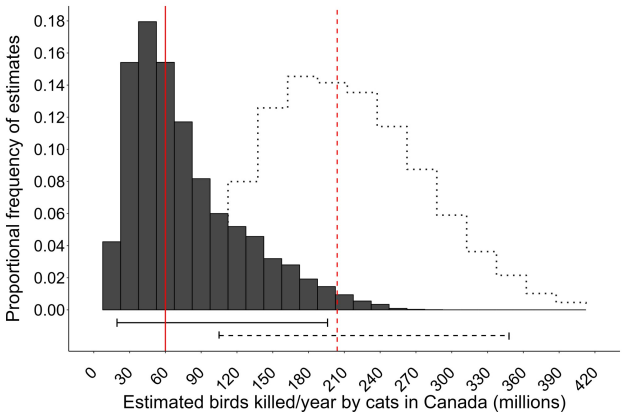
Analysis

Following Blancher (2013), we iterated the total mortality formula (K) 10,000 times, selecting a random value for each parameter within their specified distribution (Table 1). To determine how much variance in the annual mortality estimates was attributable to each parameter, we then performed linear regressions with annual bird mortality estimates as the dependent variable and estimates for each parameter as the independent variable for all 10,000 iterations.

RESULTS

Using updated predation rate values and new cat population estimates, we estimated that cats kill 60,000,000 birds annually in Canada (median, 95% CI: 19,000,000–197,000,000; Fig. 1, Table 4). Urban owned cats were estimated to kill 27,000,000 birds annually (median, 95% CI: 1,000,000–166,000,000) and rural owned cats were estimated to kill 8,100,000 birds annually (median, 95% CI: 2,400,000–21,000,000; Table 4). Unowned cats were estimated to kill 18,000,000 birds annually (median, 95% CI: 4,400,000–53,000,000; Table 4).

Fig. 1. Frequency distribution of the updated annual bird mortality estimates for all 10,000 iterations. The 95% confidence interval (19–197 million) is depicted by the solid horizontal line under the bars and the median (60 million) is denoted by the solid red line. The original distribution of estimates from Blancher (2013) is shown by the dotted lines in the background. The 95% confidence interval for this estimate (105–348 million) is depicted by the dashed line under the bars and the median (204 million) is denoted by the dashed red line.



Our revised annual bird mortality estimates were most sensitive to variation in the number of birds killed by urban owned cats (K_u), which contributed to 66% of variation in annual bird mortality (Figs. 2A, 2C). This was expected because the urban cat population was by far the largest population estimate (Table 1). The next most sensitive parameters were unowned cat population size and unowned cat predation rate explaining 15% and 5% of the variation in bird mortality estimates, respectively (Fig. 2C). Annual mortality estimates were relatively insensitive to variation in the number of rural owned cats and the predation rate of rural owned cats, both of which explained less than 1% of the variance in annual bird mortality estimates (Figs. 2B, 2C).

DISCUSSION

We report an updated estimate of the number of birds killed by cats annually (median: 60,000,000, 95% CI: 19,000,000–197,000,000) that is 71% lower than the estimates generated by Blancher (2013) over a decade earlier. Although this difference is stark, we suggest that the primary reason for these differences can be attributable to lower cat population estimates derived from field surveys in comparison to the previously relied upon pet ownership surveys and media reports of shelter intake data (Blancher 2013). Although we believe that data from field surveys are likely a more accurate representation of cat abundances across the landscape, it is important to note that they are derived from a limited number of locations across Canada (n = 5) and should, therefore, be interpreted with caution. Although surveys of cats can be costly and time consuming, additional estimates are urgently needed from a wider representation of rural and urban areas in the country. Once a wider representation can be achieved, it should then provide the opportunity to more accurately predict cat abundance in non-surveyed areas based on geographic-specific predictors, such as area, number of dwellings, shelter capacity, adoption rates, etc. A further extension of this could be multistate population models that consider how urban outdoor cat populations grow and shrink depending on factors such as shelter capacity, shelter adoption, pet cat abandonment rates, in addition to mortality, and reproductive rates (Flockhart and Coe 2018, Cove et al. 2023, Flockhart et al. 2024). This approach would necessitate a more detailed understanding of the different types of cats in the outdoor cat meta-population (indoor-outdoor, stray, feral etc.), but they are often difficult to distinguish in surveys (Lord et al. 2007, Lord 2008, Tan et al. 2021, Calver et al. 2023). Only one study focused on directly counting unowned cats (Hand 2019) and defined unowned cats as ones without collars. Although two other studies (Wilson 2025, Gow et al. 2024) have estimated the number of unowned cats based on a comparison of field survey estimates to owner survey estimates. However, there is still a substantial amount of uncertainty around the status (i.e., unowned versus owned) of cats and even within unowned cats (e.g., stray vs. feral; Patronek 1998, Woinarski et al. 2017, Calver et al. 2023).

Our lower total annual bird mortality estimate compared to Blancher (2013) can also be partially attributed to our lower predation rate parameters that were modified based on recently published studies. We included 23 additional predation studies, which lowered the median predation rate for all cat types (Table 2). Past studies (Blancher 2013, Loss et al. 2013) resampled rural

Table 4. Updated estimates of cat (*Felis catus*) populations and number of birds killed by cats in Canada. Estimates derived by Blancher in 2013 are included for comparison. Values are medians of all 10,000 iterations, with 95% range in the parentheses.

	All cats	Urban outdoor owned cats	Rural outdoor owned cats[†]	Unowned outdoor cats
Population (millions)	3.5 (1.7–5.2)	2.4 (0.9–4.1)	0.36 (0.12–0.63)	0.64 (0.28–1.0)
Percent of population		71% (43–86)	10% (3.3–25)	20% (7.5–40)
Birds killed (millions)	60 (19–197)	27 (1.0–166)	8.1 (2.4–21)	18 (4.4–53)
Percent of birds killed		51% (3.4–89)	13% (2.4–49)	30% (5.3–79)
Population 2013 (millions)[1]	7.5 (5.4–9.6)	3.3 (2.4–4.2)	1.4 (1.0–1.9)	2.8 (1.5–4.1)
Percent of population 2013		44% (34–55)	19% (14–24)	37% (23–52)
Birds killed 2013 (millions)[1]	204 (105–348)	35 (7–109)	42 (12–102)	116 (49–232)
Percent of birds killed 2013		17% (4–43)	21% (7–44)	59% (30–84)

[†] Updated rural cat population estimate includes rural cat to human density adjustment.
[1] Retrieved from Blancher (2013).

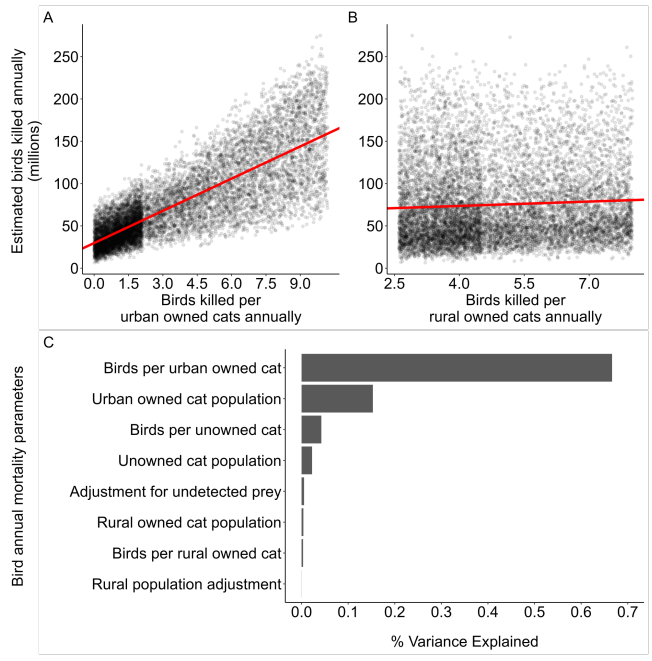


Fig. 2. Sensitivity analyses for bird annual mortality parameters. Relationship between estimated annual bird mortality with (A) number of birds killed per year per urban owned cat, *Felis catus*, ($R^2 = 0.66$), and (B) number of birds killed per year per rural owned cat ($R^2 < 0.01$). (C) is the amount of variance explained in annual bird mortality estimates by each parameter as measured by R^2 of linear regression models.

and unowned cat predation rate parameters using a uniform distribution centered around the mean because they lacked data to assume otherwise. Given that the median predation rate was lower than the mean for cat types, this approach was criticized because it may have overinflated mortality estimates (Cuddington 2019). In our study, we resampled all predation parameters assuming that 50% of values were uniformly on either side of the median, not the mean. But more research on predation rates is still needed to acquire the parameters to further refine the distribution and its shape.

One of the most highly uncertain parameter estimates used in both our estimate and Blancher's (2013) was the abundance of rural cats. To generate this value, we used Blancher's (2013) approach by applying the estimated number of owned to unowned outdoor cats in urban areas to rural areas (1.5 rural cats per urban cat) because there is some evidence that there are more cats per person in rural areas (Lepczyk et al. 2004). A more robust approach would be to directly derive abundance estimates of both owned and unowned rural cats from field-based surveys. To date, only one field study in Canada, using trail cameras, has estimated rural cat population size (Wilson 2025). However, separating owned versus unowned cats from trail camera photos is challenging in rural areas because a high proportion of owned cats do not wear collars (Lord et al. 2007, Lord 2008, Tan et al. 2021, Calver et al. 2023). Any estimates of the number of owned versus unowned cats are based on the proportion of people that put their cat outside (Gow et al. 2024, Wilson 2025), also contributing to increased variance of the estimate. Alternatively, a mark-recapture approach, where both owned and unowned cats are individually marked and then "resighted" through cameras or field surveys, may be beneficial yet costly and logistically challenging because it would require monitoring across large areas of land to accommodate the larger home ranges of unowned cats (Hall et al. 2016). Accurate cat population sizes in rural areas will be important to quantify because evidence, thus far, suggests that rural cats kill more wildlife than urban cats (Lepczyk et al. 2004, Blancher 2013, Loss et al. 2013).

Another priority to improve the accuracy of bird mortality estimates will be studies on the predation rates of cats in Canada. Currently there are no published predation rates of cats in Canada, so it is unclear if predation rates of cats from other temperate regions are applicable. Our sensitivity analysis shows that uncertainty in mortality estimates is mainly driven by urban-owned cat predation rates because of their large estimated population size (Fig. 2). On the other hand, predation parameters for unowned cats have a larger range than owned cats (Table 1) likely because predation rates vary greatly between populations

and types of unowned cats (Patronek 1998, Woinarski et al. 2017). Unowned cat predation rates primarily come from studies involving feral cats from the U.S. and Australia (Table 3). In these studies, the ecology and behavior of cats likely differ from cats in Canada because they receive little husbandry (no or very little influence of humans; Patronek 1998) and live in warmer stable climates, which allows them to hunt year-round. Whereas, in Canada, unowned cats often receive some husbandry from people through shelter or food (Van Patter and Hovorka 2017, Van Patter et al. 2019) and the colder harsher winters likely reduce predation rates during this time of year. Because bird abundance varies spatially and temporally, cat predation rates will likely also differ across Canada and over different seasons. However, it is difficult to incorporate this variation in nation-wide mortality estimates because of the lack of primary research on variation in cat predation rates in Canada or elsewhere. Additionally, accuracy of bird mortality estimates is hindered because unowned cat predation rates have been estimated from stomach contents, which can underestimate predation rates (Krauze-Gryz et al. 2012, Martínez-Gutiérrez et al. 2014). Instead, estimating predation rates using methods that directly observe unowned cat predation, such as animal-borne cameras, would increase the accuracy of unowned cat predation rates (McGregor et al. 2015, Hernandez et al. 2018, Huck and Watson 2019), allow researchers to determine predation rates of specific types of unowned cats (feral, colony cats, strays, etc.), and accordingly reduce uncertainty in nation-wide mortality estimates.

Our updated nationwide annual bird mortality estimates suggest cats are a threat to many birds in Canada and the uncertainties in our estimate have highlighted key areas where research focus should be directed. (1) Cat population estimates from additional urban areas are needed. Having cat population estimates from a wider representation of Canadian cities will increase the precision of the predictions of urban cat populations in non-surveyed areas. (2) Cat population estimates from rural areas are sorely needed. Rural cat population size has only been estimated from one location in Canada so there is much uncertainty regarding the number of outdoor cats in rural areas. (3) Predation rates from cats in Canada need to be estimated. Annual bird mortality estimates are currently derived from cat predation rates estimated outside Canada. Camera studies on cats in Canada will not only provide accurate predation rates but also information on factors such as cat behavior, habitat, and the time-of-day, which can then be used to build predictive models of predation rates in areas that are not directly sampled. We believe that improvement in these three areas will make the most significant contributions toward advancing our understanding of how cats impact bird populations in Canada. Although we have highlighted how to reduce the uncertainty of bird mortality estimates in Canada, reducing the impacts that cats have on the environment will require separate actions. These actions may include bylaws, education campaigns, social engagement efforts, and trap-neuter-release type programs but more resources are needed to implement and evaluate each approach in Canada.

Author Contributions:

J.J.C., J.B., E.A.G. conceived the study; J.J.C., D.R.N., E.A.G. designed methodology; J.J.C., O.W., E.A.G. collected the data; J.J.C., D.R.N., E.A.G. analyzed data; J.J.C. led manuscript writing. D.R.N., J.B., C.R., O.W., E.A.G. contributed to the drafts and gave final approval for publication.

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Data Availability:

All data associated with the literature review and code to reproduce the analyses and plots can be found here: https://doi.org/10.6084/m9.figshare.29801600

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Supplementary Material

Main Text: An updated estimate of the number of birds killed by outdoor cats in Canada

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Key words: avian, invasive species, Felis catus, feral, predation, predation rate, wildlife

APPENDIX

To compare with updated parameter ranges we describe briefly how Blancher (2013) set parameter ranges for their total annual mortality of birds by cats equation.

n_{owned} - *Number of owned cats in Canada*. Blancher (2013) estimated that the population of owned cats in Canada was 8.5 million (+/- 0.25). The mean was derived from Perrin (2009), who estimated that there were 8.5 million (+/- 0.01) pet cats in Canada using cat ownership survey data. This was the most recent survey and had the largest sample size (n = 7208). He increased the standard deviations to account for potential changes in cat populations since the survey was conducted.

p_r – *Proportion of owned cats from rural areas*. To account for the possibility that owned cats in rural areas imposed higher predation rates, Blancher (2013) estimated the proportion of rural owned cats in Canada by multiplying the proportion of Canadians living in rural areas at the time (19.7%) by the average number of cats in rural households. Blancher (2013) assumed rural households kept 1.5 – 2.0 times more cats than the average in urban households using data from Lepczyk et al. (2004). This resulted in a proportion of 0.27 – 0.33 owned cats from rural areas.

p_o – *Proportion of owned cats given outdoor access*. In the United States around 50-77% of cats were afforded at least some time outdoors (American Pet Products Manufacturers Association 1997, as cited in Kays and DeWan, 2004; Winter, 2004; Fiore and Sullivan, *unpubl. data*). In Canada, based on experiences of humane society

workers, it was estimated that at 70% of owned cats have access to the outdoors (Guthrie, 2009). Blancher (2013) used these two statistics and assumed the proportion of owned cats with outdoor access was between 40 – 70%.

$n_{unowned}$ – *Number of unowned cats in Canada*. Blancher (2013) estimated unowned cat populations by extrapolating the number of unowned cats per 1000 people in urban centres (reported in news articles and other grey literature) to municipalities in southern Canada (91% of the Canadian population in 2013), defined by areas excluding 78% of Canada's area that is in arctic and northern forest bird conservation areas (NACBI, 2000). He did not include feral cats in northern areas because he argued that harsh winters would prevent feral cat populations from existing. Using this approach, he estimated that the number of unowned cats in Canada ranged between 1.4 – 4.2 million.

B_u – *Number of birds brought home annually to owners by urban cats*. Blancher (2013) used nine studies from temperate regions around the world to estimate the annual number birds brought to owners per cat (Table 3). Five of the studies were conducted year-round and therefore the annual number of birds returned per cat could be taken directly. The proportion of total annual birds brought home per month was calculated form these five studies. Results from the four remaining studies that were conducted during restricted times of the year were extrapolated to an annual estimate by using the average proportion of birds returned per month. The lowest predation rate was 0.6 (Baker et al., 2008) and the highest was 6.7 (Wood et al., 2003), thus he set the

parameter range to be 0.6 – 6.7 (Table 1). He weighted the parameter's distribution by setting 50% of the re-sampled values to be on either side of the median (2.8) instead of the mean (Table 1).

B_r – *Number of birds brought home annually to owners by rural cats*. Few reliable studies existed on the number of birds brought home by rural cats, Blancher (2013) excluded two studies due to low sample size, and one study because it estimated prey return by asking participants to estimate how many items are brought back rather than report exact instances. Lepczyk et al. (2003) found that rural cats killed 20% more prey than suburban cats, so Blancher set the minimum value to be the same as the midpoint of annual urban cat prey return (2.8). The maximum number of birds brought home was set to 14 based on Eberhard (1954). Eberhard (1954) reported 31 annual bird kills per cat from stomach samples, Blancher (2013) adjusted this number downward to convert to prey returns. The parameter's range was treated as a uniform continuous distribution.

C – *Correcting for birds killed that were undetected by prey return surveys*. Because cats do not return every prey item that they hunt, prey returns can underestimate the total number of birds killed (Loyd et al., 2013; Seymour et al., 2020). To correct for this, prey returns were adjusted by the ratios of prey returns to prey kills. Blancher (2013) used a range of 2.0 – 5.8, the minimum value was informed by George (1974) that compared prey returns when cats were monitored continuously by an observer to prey returns during the average rate of monitoring. The higher end of Blancher's range was

informed by comparing scat content and prey returns (Krauze-Gry et al. 2012) and with data from animal-borne cameras attached to cats (Loyd et al., 2013).

B_f – *Number of birds killed by unowned cats.* The range of values for the number of birds killed by cats was estimated from seven studies (Table 3). Most studies analyzed scat or stomach contents to determine the number of animals killed by unowned cats. Blancher (2013) calculated annual predation rates by assuming one scat or stomach sample represents a day's diet for a cat. The minimum value of the range was set to 24, the lowest estimated predation rate (Parmalee, 1953). Blancher (2013) excluded the two highest predation rates (153, 193). This was done to be conservative because he argued that these predations rates would not apply to a majority of unowned cats. Blancher (2013) set the maximum value to the next highest predation rate of 64 (Llewellyn and Uhler, 1952).

Literature Review

To update predation rate parameters, we conducted a literature review, focusing on studies published after 2013. Studies were identified through the Web of Science database by searching for articles that contained the keywords "cat", "predation", "rate" and published between 2013–2024. We chose to use predation because it is the most ubiquitously used term used in outdoor cat literature and resulted in the widest search. Searching with other predation-related terms, such as "kill rate", "feeding rate", "depredation", etc., returned fewer articles and no articles that were not also captured using "predation". For similar reasons, we avoided terms, such as "feral", "unowned",

“pet” etc., that are not ubiquitously used by researchers. After this search returned 178 articles, we added “bird” to the keyword search, which reduced the articles to 62. Abstracts were then screened to determine if an annual bird predation rate was calculated or could be inferred through data presented in the article. Data were then extracted from the eligible papers. Primary pieces of information extracted were prey return rate/predation rate and the estimation method (Table 3). The estimated number of owned and unowned cats in Canada has been estimated in five Canadian localities: Guelph, ON (Flockhart et al., 2016), Windsor, ON (Hand, 2019), Gatineau, PQ, (Gow et al., 2024), Vancouver, BC (E. A. G., *unpubl. data*), and the south Okanagan region, BC (Wilson, 2025). We use these estimates to generate nation-wide cat population estimates.

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