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Research Paper

Estimated number of birds killed by domestic cats in Colombia

Raul E. Sedano-Cruz [1,2]

[1]Grupo de Investigación en Ecofisiología, Evolución y Biogeografía, [2]Ecología Animal, Facultad de Ciencias Naturales y Exactas, Universidad del Valle, Cali, Colombia

ABSTRACT. Wildlife mortality caused by domestic cats is evident where free-roaming house cats are present in the tropical Andes region, a phenomenon for which there is a lack of scientific reports. Our goal is to present plausible range estimates of the potential avoidable number of birds killed by domestic cats in Colombia. We calculated estimates of the number of birds killed as the product of the number of cats, the proportion of cats with at least some outdoor access, the proportion of cats that hunt wildlife, the annual predation probability, and adjustments for estimates of total prey killed by cats. We extracted such data not only from public records, but also from a citizen science study, for which we circulated a questionnaire to examine cat owners' attitudes toward the impact of domestic cats on wildlife during the 2020 and 2021 COVID-19 lockdowns in Colombia. We estimated that three to 12 million birds are killed annually by domestic cats in urban and suburban areas. In addition, we estimated that cats kill eight to 29 million vertebrate fauna in the Andes of Colombia. The total kill estimate provides a first figure on the magnitude of the impact of an anthropogenic cause of wildlife mortality for Colombia. These estimates would be more rigorous if the unowned or feral cat population size in Colombia was better known. Because most pet cats in Colombia roam outdoors without supervision and their population is growing, they pose an increasing threat to wildlife. Intervention is urgent to mitigate bird mortality by domestic cats.

Nombre estimé d'oiseaux tués par les chats domestiques en Colombie

RÉSUMÉ. La mortalité de la faune sauvage causée par les chats domestiques est évidente dans les régions où des chats de maison évoluent librement dans la région tropicale des Andes, un phénomène au sujet duquel les rapports scientifiques sont insuffisants. Notre objectif est de présenter des estimations de plages plausibles du nombre potentiellement évitable d'oiseaux tués par des chats domestiques en Colombie. Nous avons calculé des estimations du nombre d'oiseaux tués en tant que produit du nombre de chats, de la proportion de chats ayant au moins un certain accès à l'extérieur, de la proportion de chats qui chassent des animaux sauvages, de la probabilité de prédation annuelle et des ajustements des estimations du nombre total de proies tuées par des chats. Nous avons extrait ces données non seulement des dossiers publics, mais aussi d'une étude scientifique réalisée auprès des citoyens, pour laquelle nous avons fait circuler un questionnaire afin d'examiner les attitudes des propriétaires de chats par rapport à la faune sauvage pendant les confinements de 2020 et 2021 liés au COVID-19 en Colombie. Nous avons estimé que trois à 12 millions d'oiseaux sont tués chaque année par des chats domestiques en ville et en banlieue. En outre, nous avons calculé que les chats tuent huit à 29 millions de vertébrés dans les Andes de Colombie. L'estimation totale du nombre d'animaux tués fournit un premier chiffre quant à la magnitude de l'impact d'une cause anthropique de la mortalité de la faune en Colombie. Ces estimations seraient plus rigoureuses si nous connaissions mieux la taille de la population de chats inconnus ou sauvages en Colombie. Dans la mesure où la plupart des chats domestiques en Colombie errent à l'extérieur sans surveillance et où leur population augmente, ils représentent une menace croissante pour la faune sauvage. Une intervention est urgente pour atténuer la mortalité des oiseaux causée par les chats domestiques.

Key Words: *bird mortality; domestic cats; tropical Andes*

INTRODUCTION

To better understand the loss of wildlife because of the fast pace of landscape transformation, including the introduction of invasive species, estimates must be developed for risks to such biodiversity loss (Sala 2000, Mace et al. 2008). Estimates of bird mortality are key to providing an overview of the magnitude of impact on wildlife (Machtans and Thogmartin 2014), because they can help elicit awareness of the role of anthropogenic factors on the direct and indirect mortality of wildlife. The annual bird mortality caused by domestic cats is estimated to be between 1.3 to four billion individuals in the USA (Loss et al. 2013), and between 100 to 350 million in Canada (Blancher 2013). To give a sense of the magnitude of these estimates, they easily surpass direct bird mortality as a result of other anthropogenic factors in North America, including collisions with automobiles, trains, planes, buildings, windows, high tension lines, communication towers, and wind turbines, as well as the effects of pesticides, oil spills, oil pits, electrocutions, and fishing by-catch (Erickson et al. 2005, Longcore et al. 2012, Loss et al. 2013, Loss and Marra 2017).

Furthermore, in Australia, 169 to 508 million birds per year are estimated to be killed by domestic cats (Woinarski et al. 2017). Estimates of the annual bird mortality caused by house cats in the UK ranges from 25 to 29 million individuals (Woods et al.

Corresponding author: Raul E. Sedano-Cruz, raul.sedano@correounivalle.edu.co

2003). The number of birds killed by house cats in Cape Town, South Africa, is conservatively estimated at 27.5 million individuals per year (Seymour et al. 2020). These estimates provide an overview of the magnitude and importance of bird predation by house cats. In Latin America, estimates of the number of birds killed by domestic cats are lacking. The literature on the topic of domestic cats as a threat to wildlife in South America is scarce (Ferreira et al. 2014, Santiago-Alarcon and Delgado 2017, Marín Gómez 2019, Salamanca and Mora 2019), and published estimates of the numbers of birds killed by domestic cats are absent.

Several Latin American countries are part of the tropical Andes, a region that extends from western Venezuela, Colombia, Ecuador, Peru, Bolivia, and the northernmost part of Chile and Argentina. This region harbors 30% of the global bird fauna (Herzog and Kattan 2011). The introduction of domestic cats to this biodiverse hotspot can be traced back to 1511, from Europe (Inca Garcilaso de la Vega 1609, Patiño Rodriguez 1970). Genetic data clearly show that the domestic cat (*Felis catus*) was not native to the Americas (Lipinski et al. 2008), implying that the wildlife in the Americas was not previously exposed to the hunting skills of this effective meso-predator. Large numbers of domestic cats can be seen roaming freely in urban and suburban areas across the tropical Andes. It stands to reason that there has been an increase in the potential bird mortality caused by domestic cats since the introduction of this exotic mammal to the Americas.

Because of the limited sample of available studies on domestic cat predation in Latin America, we focused on Colombia, a country in the northern tropical Andes with one of the highest levels of species richness and wildlife endemism in the world. Conservation of the birds of Colombia is a goal of global significance, because it houses at least 1954 avian species of the 10,000 in the world. Unfortunately, 11% of species are threatened with the risk of extinction in this country (Renjifo et al. 2014, 2016). Threats to the bird fauna of the northern Andes include land transformation toward urbanization and agriculture, which increases the impact of domestic animals on wildlife (Renjifo et al. 2014, 2016). We argue that increased knowledge on the magnitude of domestic animals' impact on wildlife could lead to greater engagement of citizens in science-based conservation.

Wildlife predation by domestic cats is a ubiquitous phenomenon almost everywhere cats are housed with outdoor access (Beckerman et al. 2007). For instance, a citizen science–based survey in Italy documented 2042 predation events that correspond with at least 207 species killed by 145 cats (Mori et al. 2019). Even in small-scale studies, cats can have a significant impact on an impressive diversity of regional wildlife. Domestic cat predation is a direct cause of wildlife mortality, but cats can also affect bird populations through their role in disease transmission, resource competition, spatial exclusion of native species, and a fear induction (Louvrier et al. 2022), all of which compound their impact on biodiversity (Gehrt et al. 2013, Doherty et al. 2017, Loss and Marra 2017, Trouwborst et al. 2020). Pet cats, even well-fed individuals, are opportunistic meso-carnivores, which pose an additional threat to wildlife communities (Crooks and Soulé 1999, Hawkins et al. 2004). Cats have been associated in the extirpation of at least 367 species worldwide and they have been implicated in more than half of recent extinction events associated with the introduction of exotic mammals in sensitive areas (Doherty et al. 2017). It is important to stress that domestic cats may cause an unsustainable harvest in local populations (Smith et al. 1993, Crooks and Soulé 1999), as shown by computational simulations (van Heezik et al. 2010).

On the basis of previous studies, bird mortality estimates are the product of the count of domestic cats and the rate of birds killed by them (Loss et al. 2013). Such parameters are often obtained from multiple methodological approaches, including surveys (Woods et al. 2003, Kays and DeWan 2004, Mori et al. 2019) and local studies on predation by domestic cats (Gillies and Clout 2003, Seymour et al. 2020), advancements of geographic information systems over vast areas (Murphy et al. 2019), and the systematic review of existing literature on wildlife predation (Loss et al. 2013). Then, researchers impose probability distributions on the data to develop confidence intervals (Blancher 2013, Loss et al. 2013, Murphy et al. 2019). Estimates of house cat predation depends on prior data points of cat population size and the probability of taxa killed by cats over time, both of which are non-trivial estimates. Unfortunately for many countries, data on the house cat, cats with outdoor access, cats that hunt, and many other observations on this phenomenon are unavailable.

Considering prior data of the high rates of cat-caused bird mortality already shown elsewhere (e.g., U.S. and Canada, as cited within this paper), we attempted to quantify the potentially avoidable numbers of house cat kills in Colombia. Our estimates may complement efforts to describe house cat predation on wildlife, a phenomenon of particular interest for environmental authorities interested in determining if domestic cats are becoming an invasive species (Baptiste et al. 2010). In our strategy to conduct this study, we circulated a survey to urban and suburban cat owners in Colombia to estimate past prey brought home during the 2020 and 2021 COVID-19 lockdowns. The survey spatial coverage allowed for a countrywide approximation to the probability of cat predation on birds for the urbanized parts of the Andean region. In addition, data extracted from multiple official reports obtained from public records were combined to develop priors of the range of values for the number of house cats in Colombia, and the proportions of owned cats in the country as well as of cats with outdoor access. Our main objective was to conduct a data-based quantitative analysis to offer a plausible range of estimates of annual bird mortality caused by domestic cats.

METHODS

Study inclusion

We searched JSTOR, Google Scholar, and the Web of Science databases for domestic cat predation studies in Colombia and other Latin American countries. We also searched for studies providing cat population size estimates, estimates of the proportion of owned cats with outdoor access, and results of the proportion of cats that hunt wildlife. The search terms were extended by natural morphemes, including "domestic cats," "*Felis catus*," "owned cat," "pet," "outdoors," "population," "demographic," "tropical Andes," "Latin America," "cat prey," "predation," "diet," "food items," "mortality," "wildlife," "bird," "snakes," "lizard," "reptiles," "amphibians," "frogs," "mammals," "rodents," "bats," "marsupial," and "hunt." The searches were

Table 1. Range of values for each parameter used in calculation to estimate bird kills in Colombia. Acronyms used in algorithm are listed for each parameter

Parameter[†]	Acronym	Range of Values Assumed
Number of house Cats in Colombia	*nPC*	1.6–3.5 million
Percent of cats with at least some access to the outdoors	*pOd*	53–93%
Percent of cats that hunt wildlife in Colombia	*pPH*	59–70%
Birds returned home by cat per year	*BbP*	1.1–1.6 (midpoint 1.3) million
All vertebrate fauna returned home by cat per year	*VbP*	2.6–3.6 (midpoint 3.1) million
Adjustment for birds killed by cats returned and detected by owners	*Adjust*	2–5.8x
Number of unowned or feral cats in Colombia	*nFC*	*nPC* * 47%
Percent of unowned cats with access to outdoors	*fOd*	100%
Proportion of unowned cats that hunt wildlife in Colombia	*pfH*	70–90%
Birds killed by unowned cats per year	same as *BbP*	
All vertebrate fauna killed by unowned cats per year	same as *VbP*	

[†]The formulae used to estimate the number of birds killed by owned cat per year *(BKo = nPC* x *pOd* x *pPH* x *BbP* x *Adjust)*, the number of birds killed by unowned or feral cat per year *(BKf = nFC* x *fOd* x *pfH* x *BbP* x *Adjust)*, the number of vertebrate fauna killed by owned cat per year (*VKo = nPC* x *pOd* x *pPH* x *VbP* x *Adjust)*, and the number of vertebrate fauna killed by unowned or feral cat per year (*VKf = nFC* x *fOd* x *pfH* x *VbP* x *Adjust*).

conducted in both Spanish and English, and included combining multiple terms. We selected reports that clearly stated the proportion of the number of humans per cat in a given locality. Other technical reports were selected if they provided methodological descriptions, clear data on cat population size, or the proportion of cats with outdoor access in urban or rural areas at any municipality. We adopted the term "municipality" as the primary socio-political unit to aggregate data, because this term is commonly used as a spatial unit in Colombia to group data in official and technical reports.

Survey on ranging behavior of cats

A survey questionnaire to determine cat owners' attitudes toward the impact of domestic cats on wildlife was circulated from March to June 2020 as well as in 2021. The survey was built as an online questionnaire, made in KoboToolbox (https://www.kobotoolbox.org). It was distributed to contacts who shared it through WhatsApp, Twitter, and Facebook, and the forms were also sent to e-mail contacts nationwide to further propagate the survey. Cat owners were requested to record, in as much detail as possible, the prey items brought back home. The following data were also recorded: total number of cats in the household, number of household occupants, municipality of residence, and questions about attitudes of owners toward their pet cat behaviors. Similarities among surveys circulated in 2020 and 2021, including the spatial coverage in Colombia, suggest that both represent a sample of cat owners in the country that have access to the internet. A limitation of this survey strategy is that it provides no guarantee of a representative sample of cat owners in the country who lack access to the internet. An advantage of our survey strategy is that it provides an opportunity to estimate wildlife mortality over a broad zoogeographic realm in the northern Andes region.

We asked cat owners to identify past prey brought home and to further estimate the past prey returns of their pet cats in the last 45 days during the COVID-19 lockdown in 2020 (late March to mid-June) in Colombia. That was an opportunity to collect observations from pet owners who spent more time than usual at home, which was an attempt to mitigate a source of bias because of cat owners spending little time at home with their pets. Using the same rationale, a second questionnaire was launched during a major COVID-19 peak (late March to mid-June 2021). After circulating surveys in 2020 and 2021, we attempted to quantitate the variability from one year to another, in order to mitigate bias in predation probability estimates.

Owned cats definition

Owned cats are defined as those that spend at least some time indoors and most are granted outdoor access (Blancher 2013), which is important, because the time a cat spends outdoors is a determinant of predation rates (Barratt 1998). Despite the limited data in Colombia, we classified unowned or feral cats as those that roam without any supervision, a population that appears to be abundant in this country. It is important to acknowledge that some entries in our survey may be unowned or feral cats that have at least some anthropogenic-subvention in urban cat colonies (Secretaría Distrital de Salud de la Alcaldía Mayor de Bogotá 2015) .

Number of birds killed by domestic cats in Colombia

We followed an approach used in previous studies to estimate the number of cats and the average number of birds killed by cats per year (Blancher 2013, Loss et al. 2013). Because of the limited data in Colombia on the ranging behavior of cats, we did not group the data in any way except for owned versus unowned, or feral, cats. The formulae used to estimate the number of birds killed by owned cat per year had five parameters: *BKo = nPC* x *pOd* x *pPH* x *BbP* x *Adjust* (Table 1). Where *nPC* is the number of domestic cats in Colombia, *pOd* is the proportion of owned cats with at least some outdoor access; *pPH* is the proportion of pet cats that hunt wildlife; *BpP* is the annual predation probability observed by owners per cat; and *Adjust* is an adjustment for the shortcomings in owners' estimates on prey brought home and total prey killed by cats.

Estimates of the number of birds killed by cats were calculated as the product of the formulae above, after selecting a value at random for each parameter from prior data-points, which were based on a plausible range of values for each parameter (Table 1). By using this method, all priors were treated as ranges of values

with uniform distribution of probabilities. The Monte Carlo process of selecting values at random for each parameter was repeated 10,000 times to produce a 95% confidence interval of birds killed annually by domestic cats. Sensitivity of estimates to variance on individual parameters was measured using the R^2 values, with bird mortality estimates as the dependent variable in a linear regression for the parameters of the formulae above. All the analyses above were conducted in R (R Foundation 2020).

Number of cats in Colombia (*nPC*)

The estimate of the cat population size in Colombia comes from the sum of local reports of pet cats for 1056 municipalities and districts in Colombia (Subdirección de Salud Ambiental 2017). An update of this report for rabies vaccination coverage provides data that suggest a potential 16% increase compared to the report in 2017 (Ministerio de Salud y Protección Social 2019). Previous data on a small number of these localities suggest that the 2017 official report may have underestimated the cat population size at minimum in some municipalities and districts (Santafé-Osorio 2004, Ospina and Gómez Sánchez 2011, Secretaría Distrital de Salud de la Alcaldía Mayor de Bogotá 2015, Unidad Ejecutora de Saneamiento del Valle del Cauca 2016, Subdirección de Salud Ambiental 2017, Pulido et al. 2019, Correa-Duarte and Wilches-Watson 2020, Eslava-Bautista and Estupiñan-Velandia 2020, Gelves-Leal and Abdala-Logreira 2020, Amaya-Martínez and Amado-Valencia 2021). Thus, we used this estimated point value as the lower bound of the size of the cat population.

We implemented an ancillary approach to estimate the upper bound. The number of cats in Colombia may also be estimated as the product of the proportion of human to cats, multiplied by the human population size. The data from 49 municipalities and districts across the Andes of Colombia (Santafé-Osorio 2004, Ospina and Gómez Sánchez 2011, Ministerio de Salud y Protección Social and Organización Panamericana de la Salud 2012, Secretaria de Salud de la Alcaldía de Cali 2016, Unidad Ejecutora de Saneamiento del Valle del Cauca 2016) were used to calculate the proportion of humans to cats as nine to one. We followed guidelines from the Ministry of Health and Social Protection to calculate the proportion of humans to cats adjusted to the population size (Ministerio de Salud y Protección Social 2019). In a few cases, there were multiple estimates of such proportion for different sectors within a metropolitan area (Arismendy et al. 2010, Florez and Solano 2019, Pulido et al. 2019, Correa-Duarte and Wilches-Watson 2020, Eslava-Bautista and Estupiñan-Velandia 2020, Gelves-Leal and Abdala-Logreira 2020, Amaya-Martínez and Amado-Valencia 2021). This averaged proportion estimate of nine to one, humans to cats, accounts for variability in population size of both small and large cities in the Andes of Colombia (Appendix 1).

Human population size is defined here to be smaller than the 48.2 million people registered in Colombia (DANE 2018). This is because the geographic coverage of the surveys in 2020 and 2021 mainly included the Andean region of Colombia and a few additional localities outside de Andes (Appendix 2). The Andean region of Colombia is inhabited by 70% of the population, and we used latest updated census (DANE 2018) of the demographic subset for the Andean region. The number of inhabitants was divided by the ratio of humans to cats that resulted in an estimate of cat population size for the Andean region of Colombia. The two estimates above constitute the lower and upper bound bracketed range of value for *nPC* that were used for further parameter estimation (Table 1).

The proportion of domestic cats with at least some outdoor access (*pOd*)

Because most cats in Colombia are allowed to roam according to data extracted from multiple official or technical reports, it is reasonable to assume that pet cats confined to a household are less likely to contribute to the killing of wildlife outdoors. A bracketed range of values in Table 1 accounts for reasonable bounds of *pOd* (Appendix 3). These were obtained by including data from our survey in 2020 and 2021 as well as extracting the relevant portion of data from multiple official reports (Santafé-Osorio 2004, Ospina and Gómez Sánchez 2011, Ministerio de Salud y Protección Social and Organización Panamericana de la Salud 2012, Secretaria de Salud de la Alcaldía de Cali 2016, Unidad Ejecutora de Saneamiento del Valle del Cauca 2016). In some cases, multiple estimates at different scales both spatial or population size–wise were available within an urban center (Florez and Solano 2019, Pulido et al. 2019, Correa-Duarte and Wilches-Watson 2020, Eslava-Bautista and Estupiñan-Velandia 2020, Gelves-Leal and Abdala-Logreira 2020, Amaya-Martínez and Amado-Valencia 2021).

Owned cats that hunt wildlife (*pPH*)

We used data from our surveys that inquired if pet cats ever hunted wildlife. The questionnaire asked cat owners to identify past prey brought home including birds, snakes, lizards, frogs, rodents, bats, marsupials, arachnids, insects, and non-animal items. If cats only brought home items other than animals exclusively, then these cats were considered less likely to hunt. Therefore, the proportion of cats that hunt animals to the cats that do not was calculated by subtracting all cat entries with exclusively non-animal items brought back to the owner, from the list of cats that brought prey home. This proportion of cats that likely hunt was used for further parameter estimation (Table 1).

The annual predation probability (*bPE* and *vPE*)

The data from our survey on cat owners' estimates of past prey returns within a 45-day window was converted to an annual predation estimate per cat. The annual number of birds killed per cat (*bPE*) and for all vertebrate fauna (*vPE*) are static values estimated from surveys in 2020 and 2021. Estimates for these years were not combined; instead they were used to bracket the lower and upper bound range of value for *bPE* and *vPE* (Table 1). A uniform distribution was used for the Monte Carlo sampling on prey returned per cat, per year, with 50% of values between the low value and midpoint and 50% between midpoint and high value.

Adjustment for birds killed by cats versus returned and detected by owners (*Adjust*)

A correction factor for the proportion of past prey brought home to the actual prey hunted is a necessary adjustment for predation rate because most owners fail to perceive the magnitude of predation among cats (McDonald et al. 2015). Therefore, a cat owner recollection of the number of past preys returned is an

incomplete sample of animals killed by domestic cats. The proportion of prey brought home was estimated to be only 23% of total prey killed (Loyd et al. 2013). An adjustment factor of 2x can account for prey not returned home, according to a local study (George 1974); however, Kays and DeWan (2004) found that outdoor-cat killings were 3.3x as high as the number of preys returned. A recent study suggests a correction factor of 5.56x to account for prey not returned home (Seymour et al. 2020) and even a 5.8x adjustment for prey returns to prey killed was calculated by Blancher (2013), whose group used the raw data from an analysis of scats and the stomach content of cats (Krauze-Gryz et al. 2012). Here, we used a range 2.0 to 5.8x, a bracketed adjustment factor that accounts for prey not returned home within the range of values that encompassed most studies above (Table 1).

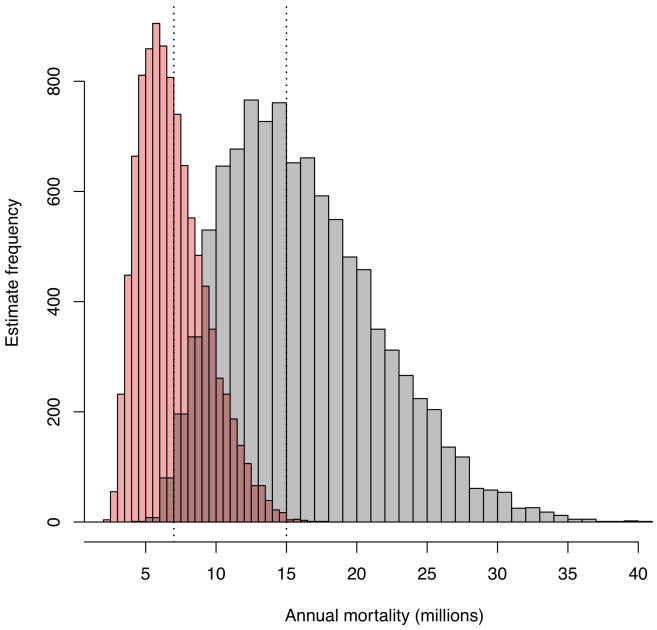
RESULTS

Our main result is an estimated range of bird mortality caused by domestic cats. Such estimates incorporate the distribution of parameters for owned and unowned or feral cats in separate analyses that were summed after using a Monte Carlo sampling process with 10,000 iterations. It was estimated that domestic cats in Colombia annually kill some three to 12 million birds (median = seven million; Fig. 1). Forty-five percent of the variation in annual bird mortality was a result of the adjustment factor on the proportion of prey brought home versus the actual prey hunted by house cats (*Adjust*). Because cat population size (*nPC* + *nFC*) explained 27% of variation in bird mortality estimates, it is clear that our estimates reflect our current uncertainty on cat population size in Colombia. In addition, to better understand the main results here, our estimates of bird mortality for owned and unowned cats varied with 78% difference among mean values. Such a large difference was primarily because we have selected conservative priors. Thus, the predation probabilities for unowned cats were assumed equal to that of owned cats (*BbP*). We also estimated the unowned cat population size (*nFC*) to be roughly 47% of the owned cats (*nPC*). It stands to reason that such assumed priors will likely contribute to underestimating the number of birds killed by cats.

In sum, our strategy to accommodate relevant parameters on this phenomenon and to develop estimates on *nPC*, *pOd*, *pPH*, *BbP*, *VbP*, *nFC*, *fOd*, *pfH*, and *Adjust* (Table 1), as well as the estimates of vertebrate fauna killed by unowned cats, are conservative assumptions that resulted in minimum cat predation estimates. This further implies that actual numbers of birds killed by cats may be even greater than current estimates (Loss and Marra 2017). It is worth mentioning that all parameters but the *Adjust* factor were based on multiple working documents and technical reports extracted from public records in Colombia. Additional research on cat population size and the probability of birds preyed upon by cats will increase the rigor of estimates of the impact on birds throughout large and small cities in the northern Andes.

In their survey responses, cat owners recollected that most cats have brought home prey of various vertebrates, arthropods, and insects. Besides the magnitude of bird mortality, we also calculated (Fig. 1) a plausible 95% confidence interval of mortality estimates for small rodents, bats, marsupials, frogs, lizards, snakes, and birds altogether. Annually, 8 to 29 million (median = 15 million) vertebrate animals are estimated to be killed by domestic cats in Colombia.

Fig. 1. Estimated probability distribution of annual mortality estimates on birds and vertebrate fauna caused by both owned and unowned or feral domestic cats in Colombia. The distribution of annual mortality estimates on birds (orange) is stacked on the distribution of vertebrate fauna (grey). The estimated median value for each distribution is shown as dotted vertical lines, the probability distribution shown for vertebrate fauna is the sum of mortality estimates for birds, lizards, snakes, frogs, small rodents, bats, and marsupials altogether.



Birds make up the majority of vertebrates preyed upon by cats. The deployment of the survey twice was an attempt to increase the accuracy of the development of estimates on prey returned over a 45-day period. It shows some variation among years: 19% of owned cats brought bird prey back home in 2020 and 17% in 2021. The mean number of cats per respondent was 1.9 ±2.1 in 2020 and 2.2 ±3.3 in 2021. The proportion of humans to cats in a household was 2.3 (±1.4):1 in 2020 and 1.5 (±1):1 in 2021, which suggests respondents were couples or single people rather than greater family nuclei. Our initial strategy to propagate the survey was a seed of three people who sent an invite to fill the e-questionnaire to roughly 2000 contacts. The first round of contacted individuals may or may not have shared the survey with their own contact lists. Because of this strategy to reach cat owners, it is not possible to know the percentage of those who responded to the survey. At any rate, we had 364 replies in 2020 and 301 in 2021.

DISCUSSION

By developing a data-based quantitative analysis, our results suggest that birds are overrepresented in estimates of cat-induced mortality compared to other vertebrates. Here, the quantitative analysis covers the most populated areas in the northern Andes and, therefore, where most domestic cats are housed. These estimates should be considered very conservative, because there are no reliable estimates of unowned or feral cats yet. It may

appear challenging to interpret an estimate of mortality of three to 12 million birds per year (median = seven million). Clearly, estimates of human-related sources of direct avian mortality reveal how important pet cat predation actually is (Calvert et al. 2013).

Our estimates of annual cat predation on bird fauna may imply a threat to small local populations characterized by lower abundances. Lower abundances in bird populations are often the case in the tropical areas despite high species diversity (Kikuchi et al. 2018). Because domestic cats have become a serious problem for population management of endemic species (Kazato et al. 2020), this may be a potential avoidable problem in hotspots for endemism of birds, reptiles, amphibians, and mammals in the tropical Andes (Orme et al. 2005). A meaningful examination of the potential effect of cat predation on population decline will require long-term monitoring, which is in itself a non-trivial task for assessing local extinction of Andean birds (Palacio et al. 2020, Sedano-Cruz and Navarro-Vélez 2022).

The pattern of human and domestic animal occupation in Colombia relates to the history of major land conversion in the Andean region (Pizano and Garcia 2014). This socio-economical aspect of urbanization and agriculture in the Andes is one important factor that leads to the insularization of remnant habitats (Alvarado-Solano and Otero-Ospina 2015, Gonzalez et al. 2016). On islands, fauna is highly sensitive to cat predation (Courchamp et al. 2003, Bonnaud et al. 2011, Medina et al. 2011, Nogales et al. 2013), and this may also apply to small isolated populations that inhabit the rugged topography of the tropical Andes. This is a region where population isolation is one inextricable driver of Andean bird evolution (Mauck and Burns 2009, Sedano and Burns 2010, Gutiérrez-Pinto et al. 2012, Valderrama et al. 2014). Thus, recurrent extirpation of isolated bird populations by domestic cats may have the potential to erode patterns of diversity accumulated over contemporary timescales.

Our study offers a plausible range of estimates that suggest a substantial annual bird mortality caused by domestic cats in Colombia. Although prey selected by cats closely reflect prey availability (Flux 2017), our survey provides an incomplete sample of prey because taxa returned are likely to differ substantially from total preyed taxa (Loyd et al. 2013, McDonald et al. 2015, Mori et al. 2019, Seymour et al. 2020). In addition, several studies provide evidence that domestic cats also cause substantial mortality of reptiles (Mori et al. 2019), small mammals (Doherty et al. 2017), and amphibians (Loyd et al. 2013). Domestic cats affect a wide range of wildlife and this may be especially important in the northern Andes, where wildlife is available all year round as compared to changes in prey availability because of the seasonality in temperate regions (Krauze-Gryz et al. 2017).

We suggest estimates of wildlife mortality presented here are of particular concern within the context of urbanization and the loss of biodiversity (Palacio et al. 2018). The cat population of Bogotá, a city of eight million people, increased in size by 123% between 2004 and 2012 (Secretaría Distrital de Salud de la Alcaldía Mayor de Bogotá 2015, Pulido et al. 2019). During the same period, the cat population of Cali, a city of 2.7 million people, increased in size by 47% (Santafé-Osorio 2004, Ospina and Gómez Sánchez 2011). The increasing urbanization and population growth in both large and small cities in the northern Andes (Schoolmeester et al. 2016), and the growing numbers of domestic cats, will lead to an increased bird mortality in urban and suburban areas. From a conservation and moral perspective, cat owners are urged to take immediate actions to prevent mortality of birds by their pet cats, in the context of the magnitude of impact on wildlife and its significance as a moral cost (Loss and Marra 2017, Nemes 2018).

The impact of cats on wildlife mortality may be increased by land use transformation and landscape homogenization, as those processes continue to insularize habitats worldwide (Rodríguez-Echeverry et al. 2018, Donald et al. 2019). Consequently, the joint effect of diverse anthropogenic-related sources of wildlife mortality accelerates the erosion of biological diversity (Brooke et al. 2008, Norris 2008). In a broad context, our study provides data-based estimates that should be part of the debate on the ethical challenges ahead caused by the impact of owned and unowned cats on Andean birds. Our estimates provide important preliminary baseline data on this phenomenon in South America, and add to a growing body of scientific reports on this critical mortality source for wildlife fauna.

CONCLUSION

Domestic cats constitute an important threat to small-bodied vertebrates throughout the urban and suburban centers in the northern Andes. However, birds are overrepresented in cat-based mortality estimates as compared to other vertebrates. The potential mortality of birds caused by house cats will likely augment in concomitance with the growth of cat populations as urbanization trends continue. To us, such estimates on cat predation signify the potentially avoidable mortality of threatened wildlife in Colombia. Our data-based quantitative analyses support the former categorization of the high risk posed by domestic cats as an invasive species in Colombia (Bapatiste et al. 2010). To move forward, a clear implementation of a citizen science program using dialectic reasoning is necessary to engage the public in effective conservation efforts. Finally, our assessment on the magnitude of cat predation in one of the most densely populated areas of the northern Andes, ~511 years after the introduction of this exotic carnivore in a hotspot of biodiversity, suggests that domestic cats may act as agents of change to the regional group of birds. Also, data-based quantitative analyses will be needed to assess effectiveness of any measures to mitigate the number of bird kills by domestic cats in Latin America.

Responses to this article can be read online at:
https://www.ace-eco.org/issues/responses.php/2200

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APPENDIX 1: Proportion of humans to cat for 49 localities including large and small cities in the northern Andes. In addition, data on human population, cat population size, year, and department in the country of Colombia.

Municipality[a,b,c,d]	Human population estimate[e]	Proportion of humans to cat as stated in report	Proportion human:cat corrected values[f]	Cat population size estimate[g]	Year of the report	Department
Alcalá	21779	5.3	5.3	4104	2016	Valle del Cauca
Ansermanuevo	19450	7.2	7.2	2721	2016	Valle del Cauca
Argelia	6421	5.8	5.8	1117	2016	Valle del Cauca
Cartago	132966	10.5	10.5	12717	2016	Valle del Cauca
El Aguila	11115	4.8	4.8	2340	2016	Valle del Cauca
El Cairo	10050	6.7	6.7	1491	2016	Valle del Cauca
El Dovio	8407	5.3	5.3	1584	2016	Valle del Cauca
La Union	38351	11.4	11.4	3371	2016	Valle del Cauca
La Victoria	13167	4.9	4.9	2670	2016	Valle del Cauca
Obando	15059	5.2	5.2	2905	2016	Valle del Cauca
Toro	16458	6.5	6.5	2537	2016	Valle del Cauca
Ulloa	5421	6.9	6.9	792	2016	Valle del Cauca
Versalles	7118	6.4	6.4	1118	2016	Valle del Cauca
Andalucía	17789	5.8	5.8	3073	2016	Valle del Cauca
Bolivar	13302	4.7	4.7	2822	2016	Valle del Cauca
Bugalagrande	21127	8.6	8.6	2449	2016	Valle del Cauca
Caicedonia	29726	7.2	7.2	4145	2016	Valle del Cauca
Calima	15794	8.4	8.4	1871	2016	Valle del Cauca
Guacari	34796	4.5	4.5	7716	2016	Valle del Cauca
Restrepo	16272	1.1	1.1	14740	2016	Valle del Cauca
Riofrío	14489	4.7	4.7	3112	2016	Valle del Cauca
Roldanillo	32597	7.1	7.1	4608	2016	Valle del Cauca
SanPedro	18383	6.2	6.2	2963	2016	Valle del Cauca
Sevilla	44876	8.1	8.1	5571	2016	Valle del Cauca

Trujillo	18041	10.6	10.6	1697	2016	Valle del Cauca
Yotoco	16345	6.0	6.0	2705	2016	Valle del Cauca
Zarzal	45681	6.6	6.6	6968	2016	Valle del Cauca
Dagua	36524	6.9	6.9	5290	2016	Valle del Cauca
ElCerrito	57749	12.0	11.0	4829	2016	Valle del Cauca
Florida	58342	14.6	13.0	3988	2016	Valle del Cauca
Ginebra	21241	9.3	9.3	2297	2016	Valle del Cauca
Jamundí	122030	9.4	9.4	12933	2016	Valle del Cauca
LaCumbre	11562	5.6	5.6	2049	2016	Valle del Cauca
Pradera	55831	21.3	20.3	2620	2016	Valle del Cauca
Vijes	11147	6.4	6.4	1745	2016	Valle del Cauca
Santiago de Cali	2209235	80.2	25.0	27529	2004	Valle del Cauca
Santiago de Cali	2269532	74.1	25.0	40490	2011	Valle del Cauca
Santiago de Cali	2508653	19.1	18.1	122180	2017	Valle del Cauca
Arauca	83256	8.9	8.9	9516	2012	Arauca
Sumapaz	2878	17.0	16.0	353	2012	Bogota D.C.
Los Martires	52197	18.5	17.5	6286	2012	Bogota D.C.
Sopó	18711	19.0	18.0	1216	2012	Cundinamarca
Florida Blanca strata 4-6	20691	21.5	20.5	345	2019	Santander
Florida Blanca stratum 4	NA	11.6	11.6	7572	2019	Santander
Florida Blanca stratum 1	237828	5.3	5.3	7572	2019	Santander
Bucaramanga	2010000	63.9	25.0	7978	2010	Santander
Bucaramanga quadrant 7	31701	10.0	10.0	3170	2019	Santander
Bucaramanga quadrant 17	26418	0.8	0.8	21134	2019	Santander
Bucaramanga quadrant 13	50563	7.5	7.5	6742	2019	Santander

[a]Municipalities 1-35: *Ref.* Unidad Ejecutora de Saneamiento del Valle del Cauca 2016.

[b] Municipalities 36-38: *Refs*. Secretaria de Salud de la Alcaldía de Cali, 2016, Ospina and Gómez 2011, Santafé-Osorio 2004.

[c] Municipalities 39-42: *Refs.* Secretaría Distrital de Salud de la Alcaldía Mayor de Bogotá D.C. 2015, Pulido et al. 2019.

[d] Municipalities 43-48: *Refs*. Amaya-Martínez and Amado-Valencia 2021, Correa-Duarte and Wilches-Watson 2020, Eslava-Bautista and Estupiñan-Velandia 2020, Gelves-Leal and Abdala-Logreira 2020, Florez and Solano 2019, Ospino-Salas and Gonzalez-Ospino 2019, Rangel-Largo 2019, Arismendy et al. 2010.

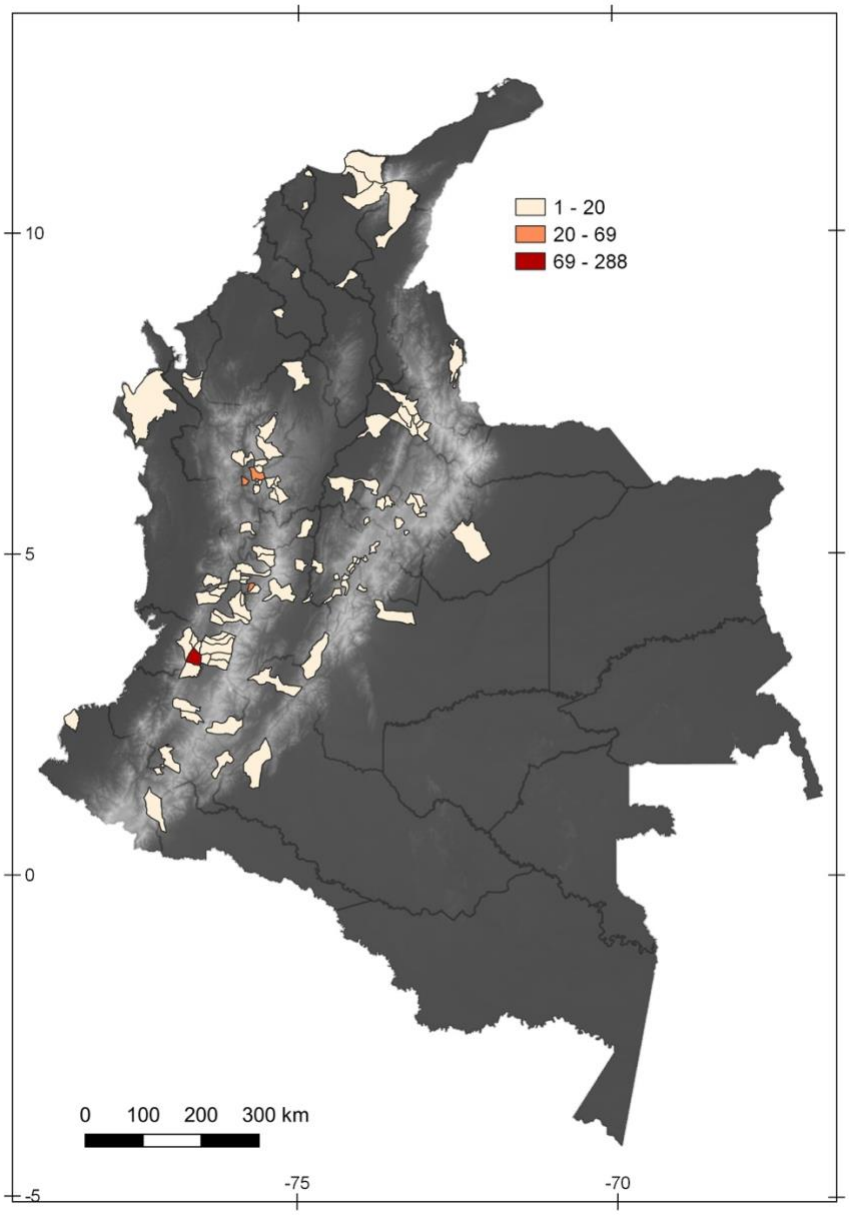
[e] Estimates of human population are intended to show variability in Andean settlements, they were obtained from the original technical report and correspond an estimate of population size to the year of the report.

[f] Statistical guidelines to average proportion of human:cat in Colombia (Ministerio de Salud y Protección Social de Colombia, 2019)

[g]The number of the cat population size in Colombia is different from the sample size used in the report to estimate human:cat proportion. Cat population size comes from the sum of local reports of pet cats for 1056 municipalities and districts in Colombia (Ministerio de Salud y Protección Social de Colombia, Subdirección de Salud Ambiental 2017). This data set was selected because it is the actual result from fieldwork survey.

NA: not available

APPENDIX 2: Spatial distribution of survey´s responses in which we asked cat owners to identify past prey brought home and to further estimate their pet cat past prey returns in the last 45 days during the Covid-19 lockdown in 2020 and 2021 (late March – mid June). Color code indicate the range of values in responses obtained from municipalities and districts in Colombia.



APPENDIX 3: Percentage of cats with outdoor access for some localities of different human population sizes. In addition, data on the percentage of unowned cats and proportion of humans to cat.

Municipality[a,b,c,d]	Human population size	Year of the report	Cat population size	Cats with outdoor access (%)	Cats with no outdoors access (%)	Range of population size	Unowned cats (%)	Proportion human to cats from reports
Sumapaz	2878	2012	353	0	100	*NA*	*NA*	17
Sopó	18711	2012	1216	36	64	649-1784	*NA*	19
Arauca	83256	2012	9516	99	1	7351-11682	*NA*	8.9
Los Mártires	52197	2012	6286	15	85	*NA*	*NA*	18.5
Pto Carreño	83433	2012	*NA*	72	28	*NA*	*NA*	*NA*
Bogota DC	7878783	2015	334666	53	*NA*	*NA*	*NA*	*NA*
Santiago de Cali	2209235	2004	27529	93.2	*NA*	*NA*	6.8	80.2
Santiago de Cali	2269532	2011	40490	76.8	*NA*	*NA*	23	74.1
Santiago de Cali	2508653	2017	122180	*NA*	*NA*	11823-132538	*NA*	19.1
Department of Valle del Cauca	see Appendix 1 for a full list of municipalities	2016	45583	71	*NA*	*NA*	*NA*	7.5
Florida Blanca strata 4-5-6	20691	2019	345	64.2	59.2	*NA*	*NA*	21.5
Florida Blanca stratum 4	NA	2019	7572	40.8	59.2	*NA*	*NA*	11.6
Florida Blanca stratum1	237828	2019	7572	52-61	48	*NA*	*NA*	5.3
Bucaramanga	2010000	2010	7978	*NA*	*NA*	*NA*	*NA*	63.9
Bucaramanga	599106 (urban)	2017	14522	*NA*	*NA*	*NA*	*NA*	*NA*
Bucaramanga stratum 7	31701	2019	3170	42	57.6	*NA*	*NA*	10
Bucaramanga stratum 17	26418	2019	21134	67	33	*NA*	*NA*	0.8
Bucaramanga stratum 13	50563	2019	6742	56.5	43.5	*NA*	*NA*	7.5

[a] 1-6: *Refs*. Secretaría Distrital de Salud de la Alcaldía Mayor de Bogotá D.C., 2015; Pulido et al. 2019.

[b]7-9: *Refs*. Secretaria de Salud de la Alcaldía de Cali, 2016; Ospina and Gómez 2011; Santafé-Osorio, 2004.

[c]10: *Ref.* Unidad Ejecutora de Saneamiento del Valle del Cauca, 2016.

[d]11-15: *Refs*. Amaya-Valencia, 2021; Correa-Duarte and Wilches-Watson, 2020; Eslava-Bautista, J. y Estupiñan-Velandia 2020, Gelves-Leal and Abdala-Logreira, 2020; Florez and Solano 2019; Ospino-Salas and Gonzalez-Ospino, 2019; Rangel-Largo, 2019; Arimendy, 2010.

NA: no available.