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Article

An investigation of bat mortality in British Columbia, Canada

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Abstract

Identifying causes of wildlife mortality can yield an understanding of the factors that impact wildlife health. This is particularly significant for species that are facing population declines because this information can inform conservation and management practices. We evaluated causes of mortality for bats in British Columbia, Canada, submitted to the provincial veterinary laboratory between 2015 and 2020, and assessed whether cause of death varied by species and (or) was associated with bat characteristics (e.g., sex and body condition). Of the 275 bats included in this study, the most frequent cause of death was cat depredation (24%), followed by blunt force trauma (23%). Bats that died by cat depredation tended to be in good body condition compared with those that died from other causes, and male bats were more likely to die from blunt force trauma compared with females. Emaciation was also an important cause of mortality (21%) and 8% of bats died due to rabies, with the greatest rabies prevalence in big brown bats (*Eptesicus fuscus* (Palisot de Beauvois, 1796)). Our results demonstrate the potential burden of cat depredation on healthy bats and highlight the need for strategies to decrease cat depredation to support healthy bat populations.

Key words: bats, British Columbia, cat depredation, Chiroptera, emaciation, mortality, trauma

Résumé

La détermination des causes de mortalité d'animaux sauvages peut permettre de mieux comprendre les facteurs qui ont une incidence sur leur santé. Cela est particulièrement important pour les espèces dont les populations sont en déclin parce que cette information peut éclairer l'élaboration de pratiques de conservation et de gestion. Nous évaluons les causes de mortalité de chauves-souris en Colombie-Britannique (Canada) remises au laboratoire provincial de médecine vétérinaire entre 2015 et 2020 et tentons de déterminer si elles varient en fonction de l'espèce ou sont associées à des caractéristiques des chauves-souris (p. ex. sexe et embonpoint). Pour les 275 chauves-souris incluses dans l'étude, la cause de mortalité la plus fréquente est la prédation par les chats (24 %), suivie des traumatismes d'impact (23 %). Les chauves-souris victimes de prédation par des chats ont tendance à présenter un bon embonpoint comparativement aux chauves-souris mortes d'autres causes, et les chauves-souris mâles sont plus susceptibles d'être mortes d'un traumatisme d'impact que les femelles. L'émaciation est aussi une importante cause de mortalité (21 %), et 8 % des chauves-souris sont mortes de la rage, les sérotines brunes (*Eptesicus fuscus* (Palisot de Beauvois, 1796)) présentant la plus grande prévalence de rage. Nos résultats font ressortir le fardeau potentiel de la prédation par les chats sur les chauves-souris en santé et soulignent la nécessité de stratégies visant à réduire la prédation par les chats pour soutenir des populations de chauves-souris en santé. [Traduit par la Rédaction]

Mots-clés : chauves-souris, Colombie-Britannique, prédation par les chats, chiroptères, émaciation, mortalité, traumatisme

Introduction

An understanding of direct causes of mortality in wildlife species, particularly those that are threatened or endangered, is needed to improve conservation and management strategies (Beaudry et al. 2008). However, the collection of data on wildlife populations can be challenging and resource intensive (Giacinti et al. 2022). Passive sampling, where citizens submit samples to government or research laboratories, is a well-established method for studies of wildlife health (Hoinville et al. 2013), and has been used to study endemic disease (Giacinti et al. 2021) as well as mortality events (French et al. 2021). This sampling technique may be especially useful for synanthropic animals (i.e., those which live in close proximity to people), because of increased opportunities for detection and submission. Although data collected by passive sampling do not represent a random sample of individuals in the environment, these data are important in understanding health issues that impact the management and conservation of species.

Bats (Chiroptera) are an ecologically and economically important group of mammals that are commonly studied through passive sampling (Harris et al. 2006; Schatz et al. 2014*a*). Globally, bats contribute to local ecosystems through pollination, seed dispersal, insect consumption, and by serving as prey for other species (Ghanem and Voigt 2012). Because of the separation of feeding and roosting sites, many insectivorous bat species in North America gather nutrients from riparian or wetland environments, where they feed, and distribute these nutrients into upland or subterranean environments, where they roost and produce guano, providing benefits for other plants and animals (Marcot 1996; Ghanem and Voigt 2012). Insectivorous bats also play an important role in pest control, consuming hundreds of insects every hour while foraging (Gould 1955). In the United States, the economic value of insectivorous bats based on their control of insect pests and the reduced need for pesticides has been estimated at greater than $3.7 billion annually (Boyles et al. 2011). For these reasons, losses in bat diversity and abundance will be detrimental to both ecosystems and economies.

Bats face numerous pressures that can result in their mortality. These include intentional extermination by humans (Hoyt et al. 2021); white-nose syndrome, caused by the fungus *Pseudogymnoascus destructans* (Blehert and Gargas) Minnis and D.L. Lindner (Pd), and is responsible for a 94% decline in populations of little brown myotis (*Myotis lucifugus*) and northern long-eared bats (*Myotis septentrionalis*) in Canada's eastern provinces (COSEWIC 2013); and wind turbine collisions (O'Shea et al. 2016) that are estimated to kill 47 400 bats annually in Canada (Zimmerling and Francis 2016). Other causes of death may be important but are not quantified in North America. For example, domestic cats (*Felis catus* Linnaeus, 1758) are the most frequently cited predator of bats globally (Welch and Leppanen 2017). Collisions with vehicles have been another cause of mortality (Fensome and Mathews 2016), and roadways also negatively impact behavior (Zurcher et al. 2010). Understanding causes of bat mortality is important because this information can be used to inform monitoring and mitigation strategies to support bat populations.

In British Columbia (BC), Canada, the causes of bat mortality are largely unknown. The province has the greatest diversity of bats in Canada, with 15 of the country's 19 species present (Nagorsen and Brigham 1993; The Western Canada Bat Conservation Program 2021; B.C. Conservation Data Centre 2022). Several species, including little brown myotis and northern long-eared bats, are endangered (Government of Canada 2021). With the detection of white-nose syndrome in bats in Washington, USA, in 2016 (Hoyt et al. 2021), and the discovery of Pd in Saskatchewan, Canada, in 2021 (Canadian Wildlife Health Cooperative 2021), there is increasing concern about the westward spread of this disease to BC, with the potential to exacerbate pressures on already vulnerable populations (COSEWIC 2013).

The aim of this study was to identify the causes of bat mortality in BC. We examined deceased bats submitted to the Animal Health Centre (AHC) in Abbotsford, BC, the province's diagnostic veterinary laboratory. Necropsies were performed to determine the likely cause of death and we retrospectively explored how cause of death related to individual characteristics and species. This study is the first to assess relative causes of bat mortality in BC and may be used to inform an understanding of local pressures on bat populations.

Materials and methods

Case inclusion

Deceased bats were submitted either fresh or frozen to the AHC, BC's provincial veterinary laboratory, from 2015 to 2020. Most bats were reported though BC Community Bat Programs (https://bcbats.ca/) by phone, email, or online form and submitted by local bat program coordinators. In some cases, bats were submitted directly to the lab from wildlife rehabilitation facilities or through another government department such as Forests, Lands, Natural Resource Operations, and Rural Development. Bats were only submitted to the AHC if they had no known human/domestic animal exposure. If bats were suspected to have been in contact with people or domestic animals, they were sent to the Canadian Food Inspection Agency (CFIA) for rabies testing. Bats were accepted during white-nose syndrome surveillance season (1 November – 31 May). From 1 June to 31 October, only bats involved in mass mortality events (more than three bats in the space of 1 week) were accepted, except during 2016 when all bats were accepted due to increased capacity through community and funding support. Case reports included information on where and when the animal was collected, in addition to the cause of death as determined by a veterinary pathologist. Wild juvenile and adult bats were included in this study if they were found dead within BC and had a completed (not pending) postmortem exam prior to the start of this analysis (June 2021). Cases in which a full postmortem examination was unable to be performed due to significant carcass autolysis prior to submission were excluded from this analysis.

Necropsy procedure

All bats were frozen prior to necropsy. A complete necropsy was performed on each bat by a veterinary pathologist to determine cause of death. Species were identified according to morphology and the bat was classified as juvenile or adult based on characteristics of the metacarpal-phalangeal joint perceived in transilluminated wings as described in Brunet-Rosini and Wilkinson (2009). The bat was examined with 385 nm UV light (LED Wholesalers, California, USA). If lesions were noted that were considered suspicious of white-nose syndrome or if the bat died between 1 November and 31 May, a swab of the wings, nose, tail, ear, and body was submitted for Pd PCR. Samples of spleen, lung, heart, liver, brain, kidney, intestine, stomach, wing, tail, ears, nose, and variably other tissues were fixed in 10% neutral-buffered formalin. To collect wing samples, one wing was deboned and placed in formalin. The tail was similarly deboned and rolled before formalin fixation. Following formalin fixation, tissues were processed routinely for histology, embedded in paraffin, and sectioned at 5 μm. All tissues were stained with hematoxylin and eosin (H&E). Wing sections, tail, nose, and ears were also stained with Periodic acid – Schiff (PAS).

Diagnostic criteria

Cat depredation was diagnosed based on the presence of characteristic puncture wounds and case history. Blunt force trauma was diagnosed based on case history and physical lesions resulting from blunt force and included collisions with vehicles, being struck by an object, and depredation by other species such as dogs that tend to crush bats in their jaws compared with cats that inflict penetrating wounds. Pneumonia was diagnosed histopathologically based on the presence of inflammatory cells in the lungs.

Emaciation was diagnosed based on body condition and the absence of adipose tissue as well as the absence of digesta in the gastrointestinal tract. Emaciation is a challenging diagnosis as bats experience wide fluctuations in body condition throughout the year, and normally have depleted adipose tissue after emergence in the spring. In this study, emaciation was considered as the cause of death if there was a complete absence of grossly and microscopically visible adipose tissue, there was subjectively low muscle mass, and there were no other apparent tissue changes visible macroscopically or microscopically to account for the death of the animal. Body condition was scored as "poor" (i.e., scant to no adipose tissue visible grossly or histologically), "moderate" (i.e., small but grossly visible fat deposits in the inguinal area and between the shoulder pads), or "good" (i.e., moderate or large deposits of adipose tissue in these areas as well as if there was grossly visible internal adipose tissue).

Pathogen testing

All bats were tested for rabies using immunohistochemistry of brain sections using internal standard operating procedures. In brief, following neutral buffered formalin fixation for 24 h, brains were embedded in paraffin and sectioned at 4 μm on a distilled water bath and picked up onto charged slides. Slides were dried in a 40 °C oven for 1 h and then a 65 °C oven for 1 h. To remove paraffin wax, slides were placed in a series of xylene, alcohol, and then water and placed into a wash buffer and then heat retrieved in ph6 citrate buffer for 15 min at 97 °C using the Agilent PT Link (Agilent, California, USA). All tissues were stained using Agilent Autostainer Link48 using a primary antibody from the CFIA and then counterstained with Harris Hematoxylin (Monoclonal, Clone 5DF12-3S35-ADRI). Positive samples were sent to the CFIA for confirmatory testing by either Fluorescent Antibody Test or immunohistochemistry and were considered positive for rabies if they were confirmed by the CFIA.

All bats were examined for the presence of fungal growth (grossly or histologically). Testing for Pd was performed via polymerase chain reactions (PCR) on all bats with suspicious lesions, and on all bats submitted between 1 October and 31 May. The PCR test for Pd was performed using the method developed by Muller et al. (2013) and results were then compared with a positive control. The positive control for this study was prepared from a fungal culture of Pd provided by the Canadian Wildlife Health Cooperative—Atlantic Region.

Statistical analyses

We recorded bat demographic and morphometric characteristics whenever possible, including species, date and location of death, sex, body condition score, presence of fungal growth (both gross and histological), and presence of dermal inflammation associated with fungal growth. The cause of death was left as "unknown" if the case report did not provide a cause of death.

All statistical analyses were run using R (R Core Team 2021) in R Studio (R Studio Team 2021) using the packages ggplot2 (Wickham 2016) and reporttools (Rufibach 2009). To analyze associations between demographic and morphometric characteristics with cause of death, we conducted Fisher's exact tests. Specifically, we assessed whether each individual cause of death was associated with: sex (male vs. female); year of death; presence of fungal growth; and body condition score (poor, moderate, or good) using Fisher's exact tests. To account for small sample sizes of different species, we first graphed each cause of death by species and visually identified potential relationships (i.e., species with appreciably large sample size showing a large proportion of individuals dying from a single cause of death). For potential relationships identified graphically, we then used Fisher's exact tests to compare the prevalence of that cause of death between the identified species and all other bats grouped together.

Results

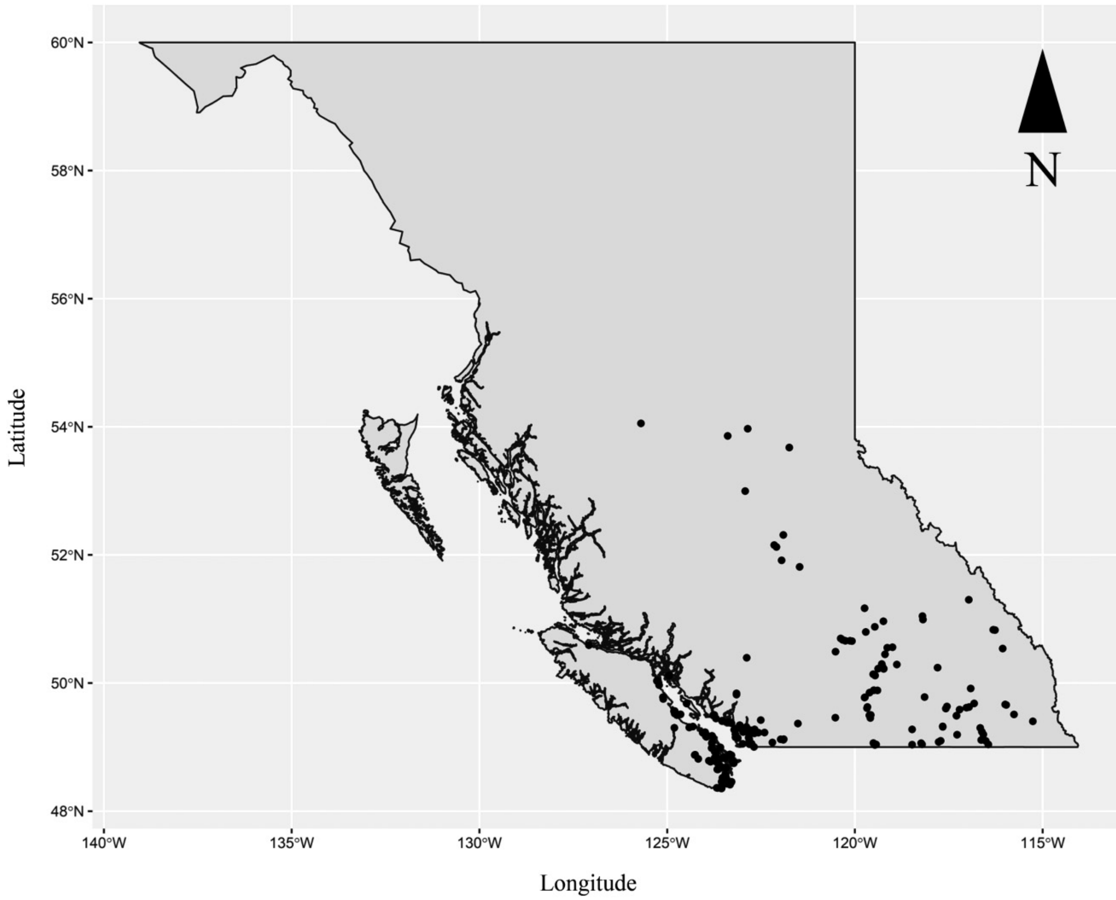
Sample characteristics

Out of 522 case reports from 2015 to 2020, 275 cases met the inclusion criteria. Bats were submitted to the AHC by members of the public ($n = 233$), rescue organizations ($n = 22$), veterinary clinics ($n = 13$), and regional parks ($n = 2$). The submission sources for five reports could not be determined. The bats submitted by rescue organizations and veterinary clinics were originally found by members of the public. Bats were submitted from across BC, with most submissions clustered around Victoria and the Lower Mainland (Fig. 1).

Most bats were submitted in the spring (March–May, $n = 112$) and summer (June–August, $n = 111$), and relatively few bats were submitted in the fall (September–November, $n = 30$) and winter (December–February, $n = 20$). The date of death was unknown for two bats.

Individuals from 12 species were submitted. In 15 bats, the species was not recorded in the postmortem report, either due to discrepancies in data reporting or carcass damage, which made it impossible to determine the species. Among bats where the species was identified, seven synanthropic species made up 91.5% of bats in our sample, while the other five non-synanthropic species made up 8.5% (Table 1) (Nagorsen and Brigham 1993; The Western Canada Bat

Fig. 1. Locations of dead bats ($n = 275$) submitted to the Animal Health Centre, British Columbia, Canada, between 2015 and 2020, which met the study inclusion criteria. Bat locations are indicated by black circles. Map generated from the British Columbia Data Catalogue with map projection NAD83 BC.



Conservation Program 2021). However, it is important to note that the delineation of certain species as synanthropic is not firmly established and is subject to debate. Sex was recorded for 220 individuals, of which 40.0% were male ($n = 88$) and 60.0% were female ($n = 132$). Eight percent of bats were juveniles ($n = 22$) and 92.0% were adults ($n = 253$). Body condition score was recorded for 243 cases, with 50.6% ($n = 123$) in poor condition, 14.0% ($n = 34$) in moderate condition, and 35.4% ($n = 86$) in good condition.

Cause of death

Of the 275 cases included in this analysis, a cause of death was determined in 91.3% of individuals ($n = 251$) (Table 1). In the remaining 24 cases, there was a lack of microscopic and macroscopic lesions, which made it impossible to definitively identify a cause of death.

The leading cause of death was cat depredation (24.0%; $n = 66$) followed by blunt force trauma (23.0%; $n = 64$), emaciation (21.1%; $n = 58$), rabies (7.6%; $n = 21$), pneumonia (4.0%; $n = 11$), dehydration (3.3%; $n = 9$), and dermatitis (2.9%; $n = 8$). Trauma were frequently anthropogenic and included collisions with vehicles, walls, and windows, being crushed in garage doors, and through direct harm from humans or domestic dogs. There were 5.1% of bats that died by other causes ($n = 14$) including septicemia ($n = 4$), drowning ($n = 2$), necrohemorrhagic colitis ($n = 2$), fetal mummification ($n = 1$), placentitis ($n = 1$), pulmonary edema ($n = 1$), suffocation ($n = 1$), systemic thrombosis ($n = 1$), and transmural intestinal hemorrhage ($n = 1$). In total, 20.7% of bats had fungal growth ($n = 57$) and 63.2% of these had inflammation associated with the growth ($n = 36$). Causes of death did not vary significantly between the year 2016, in which bats were accepted year-round, and other years in which bats were not accepted during the summer outside of mass mortality events.

Associations between causes of death and bat characteristics

Males were more likely than females to die of blunt force trauma, when compared with all other causes of death ($p < 0.01$). Although not statistically significant ($p = 0.14$), females were over-represented among bats killed by cats (67.3%) compared with the proportion of females among bats killed by blunt force trauma (39.6%) and compared with the proportion of females in the total sample (57.8%). There were no sex differences for any other cause of death.

A cause of death was determined for 236 individuals for which species were also identified (Table 1). There was an association between species and cause of death by cat

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Table 1. Cause of death for 11 bat species surveyed in British Columbia, Canada.

Species	Cat depredation	Trauma	Emaciation	Rabies	Pneumonia	Dehydration	Dermatitis	Other	Total
Synanthropic									
Big brown bat, *Eptesicus fuscus* (Palisot de Beauvois, 1796)	10	7	6	11	2		2	3	41
California myotis, *Myotis californicus* (Audubon and Bachman, 1842)	7	11	7	1			1	2	29
Little brown myotis, *Myotis lucifugus* (Le Conte, 1831)	19	14	17	2	3		2	7	64
Long-eared myotis, *Myotis evotis* (H. Allen, 1864)	10	3	5	2	1		1		22
Silver-haired bat, *Lasionycteris noctivagans* (Le Conte, 1831)†		9	3	2				1	15
Townsend's big-eared bat, *Corynorhinus townsendii* (Cooper, 1837)		2	2			4			8
Yuma myotis, *Myotis yumanensis* (H. Allen, 1864)	9	6	13		4	2	2	1	37
Non-synanthropic									
Fringed myotis, *Myotis thysanodes* Miller, 1897				2					2
Hoary bat, *Aeorestes cinereus* (Palisot de Beauvois, 1796); formerly known as *Lasiurus cinereus* (Palisot de Beauvois, 1796)		1	1						2
Northern long-eared myotis, *Myotis septentrionalis* (Trouessart, 1897)	6	4	3		1				14
Western small-footed myotis, *Myotis ciliolabrum* (Merriam, 1886)	1	1							2
Total	62	58	57	20	11	6	8	14	236

Note: Species are divided into those commonly found living in close proximity with humans (synanthropic) and those that are not (non-synanthropic). Species were classified according to Nagorsen and Brigham (1993) and The Western Canada Bat Conservation Program (2021). The delineation of certain species as synanthropic is debated.

†Silver-haired bats are sometimes considered non-synanthropic because they roost primarily in natural sites and are typically only found in human structures during migration (Klug et al. 2011).

Fig. 2. Rabies presence (black) and absence (grey) among bats ($n = 170$) across 12 bat species in British Columbia, Canada. Big brown bats (*Eptesicus fuscus*) had a higher rabies prevalence (26.2%) than all other species pooled together (4.3%; $p < 0.01$). Significant associations (Fisher's exact test, $p < 0.05$) are indicated with an asterisk (∗). For the binomen of the species listed on the *x* axis refer to Table 1.

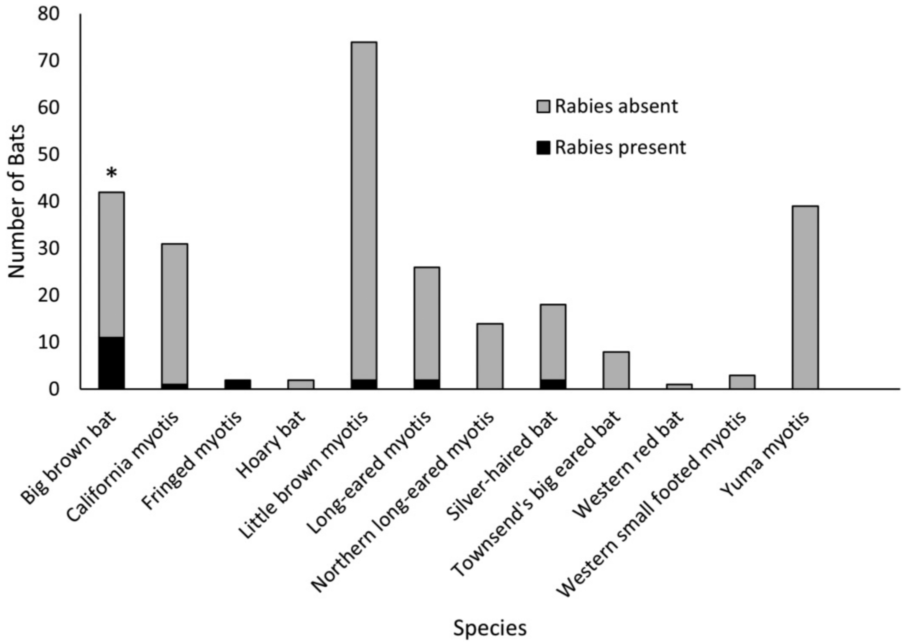
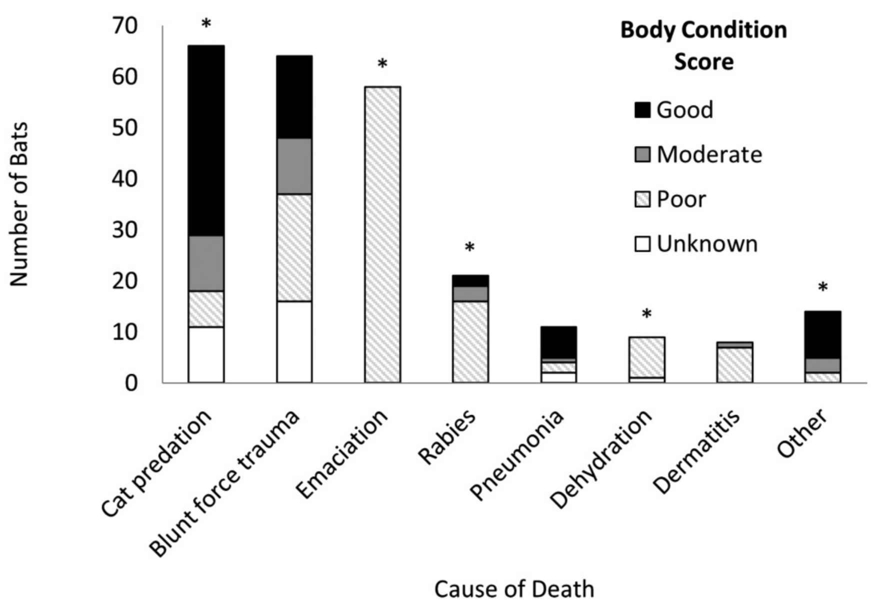


Fig. 3. Body condition score and cause of death among bats ($n = 251$) in British Columbia, Canada. Poor body condition score was associated with cat depredation ($p < 0.01$), emaciation ($p < 0.01$), rabies ($p = 0.04$), dehydration ($p = 0.04$), and other causes of ($p < 0.01$). Significant associations (Fisher's exact test, $p < 0.05$) are indicated with an asterisk (∗).



depredation ($p = 0.02$), blunt force trauma ($p = 0.03$), rabies ($p < 0.01$), and dehydration ($p < 0.01$). Sample sizes for several species were too small to test for associations with causes of death. However, cat depredation was significantly more common in little brown myotis ($p = 0.04$), and big brown bats (*Eptesicus fuscus*) had a higher ($p < 0.01$) rabies prevalence (26.2%) compared with all other species pooled together (4.3%) (Fig. 2). Of the six bats of known species that died of dehydration, four were Townsend's big-eared bats (*Corynorhinus townsendii*) that were submitted from the same mass mortality event and two were Yuma myotis (*Myotis yumanensis*) that died independently.

Cat depredation was associated with good body condition score ($p < 0.01$) (Fig. 3). This association was still significant ($p < 0.01$) when excluding emaciated bats, which are inherently associated with poor body condition. Poor body condition score was also associated with emaciation ($p < 0.01$), rabies ($p = 0.04$), and dehydration ($p = 0.04$) (Fig. 3). Bats that died by other causes of death tended to have a good body condition score ($p < 0.01$) (Fig. 3).

Pd was not detected on any bats, although 20.7% showed cutaneous fungal growth, which was significantly associated with cat depredation ($p = 0.01$) and emaciation ($p = 0.02$). Of the leading causes of bat mortality, fungal growth was most prevalent in bats that died from emaciation, with 19 out of 58 bats that died of emaciation having fungal growth (32.8%). Eleven of the 19 emaciated bats with fungal growth also had signs of inflammation associated with the fungus, suggesting that growth occurred prior to death. Fungal growth was most prevalent in the spring (36.7%), followed by winter (22.2%), fall (14.3%), and summer (5.2%). Inflammation associated with fungus was also most common in the spring (25.7%), followed by fall (10.7%), winter (5.6%) and summer (2.1%).

Discussion

From 2015 to 2020, more than half of bat deaths recorded at BC's provincial veterinary laboratory were caused by cat depredation, blunt force trauma, or emaciation. The most frequent cause of death was depredation by cats, and these bats were in better body condition compared with bats killed by other causes of death. Blunt force trauma was positively associated with male sex relative to other causes of death. Passive surveillance in this study revealed that bat deaths in BC were commonly anthropogenic, which may suggest the need for mitigation measures aimed at changing human behaviors.

Blunt force trauma more common among male bats

Trauma was a major cause of death of bats in our study. Trauma commonly impacts bats near wind energy facilities (Smallwood 2020) and through collisions with vehicles (Fensome and Mathews 2016). Although one bat in our sample was killed by trauma at a wind farm, fatalities at wind energy facilities are typically detected via active surveillance, so despite estimates that hundreds of bats are killed by wind turbines in BC every year (Zimmerling and Francis 2016), our study was unlikely to detect them. Instead, bats in our sample sustained traumatic injuries primarily through other anthropogenic causes.

In our study, we found that blunt force trauma killed a disproportionate number of males. Bats demonstrate sex differences in behaviors such as habitat use (Lintott et al. 2014), migration (Jonasson and Guglielmo 2016), and foraging (Grinevitch et al. 1995). These behaviors may create opportunities for sex-related differences in mortality. In Europe, Fensome and Mathews (2016) revealed that collisions with vehicles killed male bats more frequently than females, possibly because males fly greater dispersal distances. Habitat can also be segregated between the sexes, with males occupying poorer quality areas, thus coming into more frequent contact with roadways (Fensome and Mathews 2016). Many bats in BC have separate summer roosting sites for males and females, with females occupying warmer, low-altitude maternity colonies that meet their higher energy cost of reproduction (Nagorsen and Brigham 1993). Our results suggest that traumatic death is relatively more common among males, but whether this is due to migration or intersexual habitat differences remains unknown.

Cats depredate on bats in good body condition

Domestic cats are well-established predators of wildlife (Loss and Marra 2017; Legge et al. 2020) and bats (Daniel and Williams 1984; Woods et al. 2003; Ancillotto et al. 2013). As the leading relative cause of death of bats in our study, cats may be an important cause of mortality for bats in BC.

Studies have found that cats tend to kill birds with similar (Møller and Erritzøe 2000) or worse (Baker et al. 2010) body conditions than those killed by trauma. However, our study found that bats killed by cats were in better body condition than those killed by blunt force trauma, suggesting that this trend may not hold true for this sample of bats. This is concerning because it suggests that cats are removing bats which may be more likely to avoid other causes of mortality such as emaciation.

Bats killed by cats in our data set were disproportionately female. These findings align with Ancillotto et al. (2013) who found that 68.7% of bats attacked by cats were female. Ancillotto et al. (2013) suggest that cats may be attracted to maternity roosts because of sensory cues such as the smell of accumulated guano, the sight of bats frequently exiting the roost and the auditory detection of bat echolocation. However, it is unknown whether bats killed by cats in this study were depredated on in or near maternity roost sites. Since most female bats in BC only produce one or two pups per year (Nagorsen and Brigham 1993), these mortality events can negatively impact population abundance because they are not easily mitigated through new births. Public education about the risk of cat depredation, including at maternity roosts, coupled with design proposals to mitigate this risk may encourage cat owners to contain cats indoors (McLeod et al. 2017) and help to reduce cat depredation at roosts.

Emaciation among bats

Despite being the third most frequent cause of death in our study, emaciation is not commonly reported in bats, except in the context of white-nose syndrome (Cryan et al. 2010). *Pseudogymnoascus destructans* infiltrates the wing membranes of infected bats, disrupting normal physiology during hibernation, causing bats to expend their energy stores and leading to emaciation (Cryan et al. 2010). While white-nose syndrome has not yet been detected in BC, cutaneous fungal growth was found in 20.7% of bats and was associated with emaciation. It is possible that the fungus may have imposed a physiological cost for bats leading to emaciation, or that emaciated bats were secondarily predisposed to fungal infection. It is also possible that there may be a temporal association, as emaciation and fungal dermatitis were both more common in the spring. In cases where inflammation associated with infection is absent, fungal growth may have occurred postmortem. Further work is needed to identify the fungal species present

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on bats in BC and to investigate the physiological impacts of these fungi.

Pesticide consumption may also influence bat emaciation. First, insectivorous bats are vulnerable to pesticides through their diets (Oliveira et al. 2021). Although the physiological effects of pesticides on bats are not well understood, pesticides have been found to increase basal metabolic rate in several bat species, depleting energy reserves (Oliveira et al. 2021). Second, pesticides reduce insect populations, and thus food for bats. Although pesticides are commonly applied in BC, it is unknown whether their use contributes to emaciation in bats. Finally, roadways may contribute to emaciation because they interfere with commuting behaviors and may impede bats from accessing foraging areas (Zurcher et al. 2010).

Rabies prevalence across species

Our sample included 12 of the 15 bat species found in BC, although sample sizes varied widely by species. We found that the relative number of bats with rabies differed across species, ranging from 0.0% (i.e., little brown myotis) to 100.0% (i.e., fringed myotis, *Myotis thysanodes*). In particular, rabies prevalence in big brown bats (26.2%) was more than six times higher than in the combined sample of all other bats where the species was known (4.1%). And while a recent report of Canada-wide rabies surveillance data, which includes some of the data in this study, found that big brown bats have the highest prevalence of rabies nationally (17.1%) (Segers et al. 2021), these estimates are unlikely to reflect actual rabies prevalence. This is due to both the mode of sampling (i.e., passive) and that infection with rabies makes bats much more likely to be encountered by people than other causes of death such as dehydration (Pybus 1986; Klug et al. 2011). Specifically, passive sampling is unable to properly assess rabies prevalence because rabid bats exhibit behaviors that will bring them into contact with humans (Pybus 1986; Klug et al. 2011). For example, bats with furious rabies may be hyperactive and aggressive, while bats with paralytic rabies may be placid and appear friendly or tame, both making them more likely to be detected by people (Fenton et al. 2020). Further, non-synanthropic species do not regularly encounter humans and are therefore rarely submitted to diagnostic laboratories, which can inflate rabies estimates among individuals that are submitted. Indeed, in our study only two fringed myotis individuals were submitted, but both were positive for rabies. To properly estimate rabies prevalence in the province, active and especially targeted sampling is required to overcome the limitations of passive sampling for this pathogen (Harris et al. 2009). However, due to the logistical effort associated with active surveillance and potentially limited additional information it provides, active surveillance is not likely to eliminate the need for passive surveillance (Schatz et al. 2014*b*).

Important considerations

The bats in this study were collected using passive surveillance, which relies on spontaneous submission of carcasses. It can bias sampling toward populated urban areas (Ward et al. 2006), as well as overrepresent human-associated causes of mortality (e.g., road kills and cat depredation), and synanthropic species. Indeed, the seven synanthropic species made up >90.0% of the bats in our sample. While active surveillance is often preferable for specific questions of disease and mortality, it is difficult to conduct over a broad area and over multiple years. Therefore, this study may indicate where targeted sampling may be warranted.

Limited sample sizes make it difficult to investigate relationships between species and cause of death. For example, fringed myotis and hoary bats (*Aeorestes cinereus*; formerly known as *Lasiurus cinereus*) were each represented by two individuals, and eastern red bats (*Lasiurus borealis* (Müller, 1776)) were represented by a single individual. Additionally, samples were impacted by autolysis, which rapidly degrades bat carcasses during the summer months. As such, bats were not accepted at the AHC from June to September unless they were part of a mass mortality event. If there was a cause of mortality that commonly affects individual bats during the summer in BC, then our study may not have detected it. However, there were no significant differences in causes of death between 2016, the only year all bats were accepted year-round, and any other year, which does not point to significant changes in causes of death in summer months. Further work is needed to investigate seasonal association with bat mortality. Finally, scoring body condition and diagnosing emaciation in bats is difficult due to their small size and absence of bone marrow fat. Although our categories for body condition score were left relatively broad, some degree of subjectivity remains in the scoring process.

Conclusion

From 2015 to 2020, bats submitted to BC's provincial veterinary laboratory were frequently found to have died from anthropogenic causes, particularly cat depredation and blunt force trauma. Emaciation was also a significant source of bat mortality, although the underlying cause of emaciation was less clear. Altering human behavior through education to encourage keeping domestic cats indoors may help to reduce pressures on bats that face other risks such as emaciation or disease which may be harder to mitigate. Finally, our study highlights the value of passive surveillance for investigating relative causes of death for wildlife, but points to the need for integrating active monitoring of species to estimate the true prevalence of these causes of death and further inform conservation and management efforts.

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Data availability

The data in this study are available from the researchers upon request.

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Author contribution

This study was conceived of by GM, CGH, and KB, and KB oversaw project administration. Bat necropsies were performed by GM. Data curation was performed by IB, DS, and LL, and the formal analysis was completed by IB, ML, and KB. IB wrote the first draft of the manuscript with significant contributions by KB. All authors reviewed, edited, and approved of the final paper.

Competing interests

The authors declare there are no competing interests.

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